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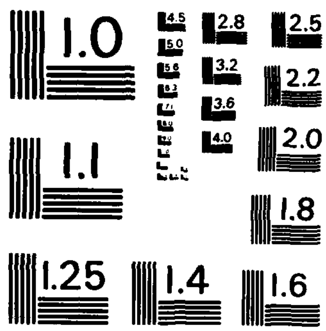

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The Human Operator and System Effectiveness

by
Ronald A. Erickson
Aircraft Weapons Integration Department

JUNE 1984

NAVAL WEAPONS CENTER
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FOREWORD

This report may be of most value to the relatively inexperienced human factors engineer who must support the analysis activities associated with a systems design effort. The human factors engineer can contribute a lot to such an effort, and insure that sufficient attention is paid to the operator performance part of the analysis. With practice, the human factors engineer can do most of the analysis, providing useful results to the rest of the design team; the results can also be used to support human operator requirements with hard numbers.

Systems engineers may also gain an understanding from this report of how operator performance considerations can be included in systems analysis and design.

The report outlines the procedures to follow in conducting a systems effectiveness analysis. The components of such an analysis, including operator performance data are described and examples are provided. Although the report does not provide specific instruction on how to do a task analysis or function allocation, or how to collect performance data, the analytic framework is provided for combining these inputs in an effectiveness analysis.

This report has been reviewed by Dr. Dave Meister, Dr. Jesse Orlansky, Dr. Charles Greening, Steve Merriman, Dr. Robert Wherry, Cdr. William Moroney, Cdr. C. Hutchins, Joe Cardani, Mike Barnes, and Joyce Madden.

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(U) *The Human Operator and System Effectiveness*, by Ronald A. Erickson. China Lake, Calif., Naval Weapons Center, June 1984. 100 pp. (NWC TP 6541, publication UNCLASSIFIED.)

(U) This report develops the procedure to follow in producing a system effectiveness analysis, including the performance of the human operator(s) of the system. The report discusses the factors associated with each step in the procedure, including choice of measures of effectiveness, the form of system component performance data, and the characteristics of some mathematical models and analysis techniques.

(U) An example is used throughout the report to illustrate the guidelines. Both a simple listing, and a flow diagram summarize the procedures; more detailed guidelines are given in tables associated with steps in the procedure.

CONTENTS

INTRODUCTION

This report develops the procedures to be followed to predict the ability of a human operator to use a system under real world conditions. Can a bus driver complete his route on time, winter or summer? Can a pilot find a target in time to attack it, in the desert or in mountains?

The end product of such an analysis is the probability of success, or the percent of the time that the system could be used successfully. Such quantitative results can provide the designers of new equipment with guidelines as to how good or poor their design is; the results can illustrate the importance of including human engineering in the design process.

Human Factors specialists have participated in the design of systems for over thirty years. The level of this participation has varied from determining the shape of knobs on a control panel to developing employment concepts that directly affect much broader design questions. The work has ranged from designing and conducting laboratory experiments and man-in-the-loop simulations to paper analyses of tasks and operational sequences.

The application of this broad range of human factors specialties to major design efforts, such as the Navy's F/A-18 aircraft has illustrated the acceptance of human factors work in the design process. That acceptance is not universal, however, and human factors people continue to worry about being included on the design team. They worry about advancing their specialty to keep up with the changing technical world, and often must "prove the worth" of human factors contributions to system design efforts.

In a survey of senior level human factors specialists conducted by Meister,[1] 64% felt that designers on their own are incapable of understanding human factors inputs. In a later survey by Meister,[2] "if new methodological approaches are needed, no one seems to know what these would be." One of the main problems cited by the respondents was that of demonstrating the worth of human factors. It should be noted that the surveys did not ask systems analysts or design engineers about human factors or the inclusion of operator performance in their work. This should be done to get a more complete description of the situation.

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[1] Meister, David, "The Influence of Government on Human Factors Research and Development," Proceedings, 1979 Human Factors Society Annual Meeting (pp. 5-13).

[2] Meister, David, "The Present and Future of Human Factors," Applied Ergonomics 1982, Vol. 13.4, pp. 281-287.

In another such survey conducted by Topmiller, et al[3], as part of a methodological study, the authors concluded that:

> "It is fairly obvious that most of the advanced thinkers in the human factors discipline believe that the greatest needs for future technology development are being driven by the requirement for a human-machine-mission (H-M-M) systems analytic and simulation capability. H-M-M systems analysis and simulation methods must be developed to treat human, equipment and mission parameters in equivalent quantitative terms in order to isolate this respective contribution to overall systems effectiveness."

Perhaps the human factors people must move further into the design process with their data, and do something with it themselves. This report will help them do that.

SCOPE

Before system performance can be predicted, it must be defined. According to a USAF Weapons System Effectiveness Industry Advisory Committee (as cited by Kline),[4]

> "System Effectiveness is a measure of the extent to which a system may be expected to achieve a set of specific mission requirements and is a function of availability, dependability, and capability."

This report does three things:

1. Gives a very brief overview of current analysis methods used in the estimation of the capability part of the effectiveness equation.

2. Discusses the factors that must be included in systems effectiveness computations.

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[3] Topmiller, Donald A., Methods: Past Approaches, Current Trends, and Future Requirements, in Manned Systems Design, edited by J. Moraal and K. F. Krais, Plenum Press, New York, 1981.

[4] Kline, Melvin B., Introduction to Systems Engineering, Lecture Notes, 1982, Naval Postgraduate School, Monterey, Calif.

3. Presents the procedures used in estimating the "capability" part of effectiveness that have been derived from several specific studies conducted by the author.[5-8] Presentation of this procedure is the major purpose of the report.

The specific, analytic efforts referred to in (3) above, were conducted in support of development programs and make provision for including human operator performance in systems effectiveness analysis. When the methodology is appropriate, it fulfills the need pointed out in references 2 and 3 above.

It should be added that there is little "new" material in this report; rather, it collects information from many sources and focuses it on how to conduct analysis.

The methodology can help to bridge the gap between the human factors specialist and the systems engineer. It can be used to quantify the importance of the operator's performance to overall system's effectiveness, and thereby demonstrate the "worth" of including human factors as a specialty in systems design.

LIMITATIONS

This report does not:

1. Present a comprehensive review of the literature in systems analysis, or critique other analytic methods or procedures.

2. Deal with cost-effectiveness. Economic factors must be considered at all stages of system design and acquisition. Cost-effectiveness tradeoffs must be performed, but we are concerned in this report only with the system performance part of the equation.

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[5] Naval Weapons Center. Launch Opportunity for Air-to-Ground Visually Delivered Weapons, by Ronald A. Erickson and Carol J. Burge, China Lake, Calif., NWC, January 1978. (NWC TP 6005, publication UNCLASSIFIED.)

[6] -----. Anti-Ship Missile Study; Man-in-the-Loop Operation, by Ronald A. Erickson, China Lake, Calif., NWC, November 1979. (NWC TP 6112, publication UNCLASSIFIED.)

[7] -----. Another Anti-Ship Missile Study; Man-in-the-Loop Operation, by Ronald A. Erickson, China Lake, Calif., NWC, February 1981. (NWC TP 6236, publication UNCLASSIFIED.)

[8] -----. Air-to-Ground Weapon Delivery From Level and Pop-Up Flight Profiles, by Ronald A. Erickson, China Lake, Calif., NWC, August 1981. (NWC TP 6291, publication UNCLASSIFIED.)

3. Explicitly address human error in systems operation. No methods are presented which show how to estimate the probability of pushing the wrong button, or making the wrong turn. Although very important in system design, human reliability is beyond the scope of this report.

4. Consider the human factors aspects of system maintenance and repair.

The scope of this report is therefore limited further in relation to the above USAF definition of system effectiveness. We are concerned with predicting a manned system's capability (or performance), given that it is available and dependable (i.e., that nothing breaks). Availability and dependability will not be addressed.

BACKGROUND

The following section is intended to be tutorial in an overview sense; it is intended to give an idea of what a system is, and to describe what is done in the systems analysis process. Selected quotes from the literature are used when possible. Other quotes on the same subject that were assembled in the course of this study are given in Appendix A. The purpose of including Appendix A is to give the inquisitive reader a variety of comments by several senior specialists in the field.

SYSTEMS

This study deals with systems which include human operators. Many definitions of such systems have been given in previous publications; some are given in Appendix A. The author's definition that fits the topic of this report is given below.

> A man-machine system is a set of interacting components composed of humans and machines (including software) directed toward performing a function or number of functions and operating within the constraints of time and specified environments.

It is not important at this point to determine if the above definition is "better" than the others. Suffice it to say that the specific make-up of a system is in the eyes of the beholder. That make-up is composed of physical entities that can include humans. The systems we are concerned with here are designed to perform a function (or functions), and we are concerned with whether or not, or how well they can perform that function.

We would like to estimate the effectiveness of the system as a function of the operators' abilities, the operating conditions, and the kind of tasks and tools (e.g., controls and displays) in the system.

In statistical terms, we would like to estimate the variance contributed to system effectiveness by the operators so that it can be compared to the variances contributed both by major components in the total system and by environmental factors.

SOURCES OF INFORMATION

There are many analytic, or mathematical techniques that have been used in the prediction of system performance, and specialties have emerged around these techniques: systems engineering, systems analysis, and operations research. There is a certain amount of overlap in these specialties, as illustrated in Figure 1 (as suggested by Singleton[9]). Much of the literature can be grouped into four categories, according to the content of each. Brief comments about these four categories are given below.

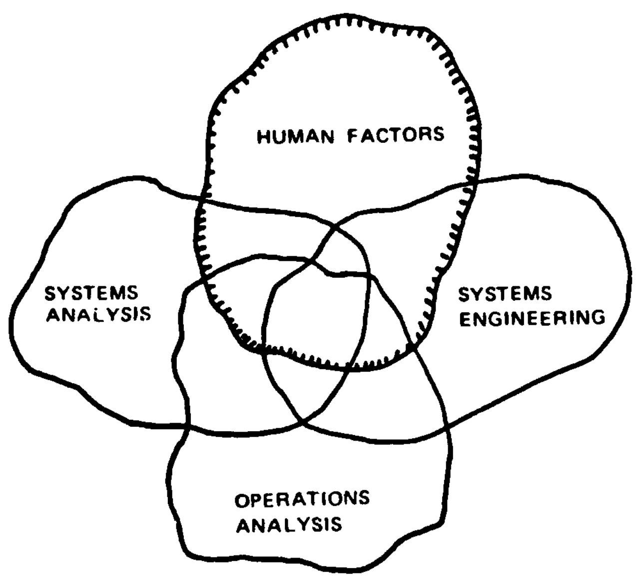

FIGURE 1. Overlap in Specialties.

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[9] Singleton, W. T., "Ergonomics in Systems Design," ERGONOMICS 1967, Vol. 10, No. 5, pp. 541-548.

System Development and Analysis[10,11,12]

These types of books outline the processes to be followed in developing a system and observations are made about each step in the process. Man-machine factors or interfaces are sometimes mentioned explicitly, and some analytic techniques found in human factors (e.g., task analysis) are mentioned, but specifics are rarely given. These texts are useful references when working as part of a design team.

Human Factors[13,14,15,16,17]

Most of the articles in this category say that human factors should be included in systems development procedures. The history of human factors and general requirements for its use are given. Several of these articles are of th "human factors people should . . .," or "engineers should . . . " variety. T overview articles were not intended to relate one-on-one with handbooks t give specific human performance data. Hopefully this report will provide on the missing links by giving all of the analysis procedures to follow from star to finish.

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10 Chase, Wilton P., Management of System Engineering, John Wiley and Sons, New York, 1974.

11 Wilson, Warren E., Concepts of Engineering System Design, McGraw-Hill Book Company, New York, 1965.

12 Chestnut, Harold, Systems Engineering Methods, John Wiley and Sons, Inc, New York, 1967.

13 Meister, David, Behavioral Foundations of System Development. John Wiley and Sons, New York, 1976.

14 Meister, David, and Gerald F. Rabideau, Human Factors Evaluation in System Development, John Wiley and Sons, New York, 1965.

15 Meister, David, "Systems Development: The Future of Ergonomics as a System Discipline," ERGONOMICS 1973, Vol. 16, No. 3, pp. 267-280.

16 Jones, J. C., "The Designing of Man-Machine Systems," ERGONOMICS 1967, Vol. 10, No. 2, pp. 101-111.

17 DeGreene, Kenyon B., "Major Conceptual Problems in the Systems Management of Human Factors/Ergonomics Research," ERGONOMICS 1980, Vol. 23, No. 1, pp. 3-11.

Development/Analysis/Research Tools[12,18,19]

Many texts, articles, and reports discuss the analytic or mathematical tools used in particular applications (e.g. cueing theory, linear programming). These are sometimes, but not often, put in an overall systems development context. Human factors analysis, or a requirement for human performance data is seldom mentioned. The texts are necessary, however, in determining which mathematical techniques to use in an analysis.

A Specific Problem[7,8]

Technical reports document studies designed to solve specific problems and sometimes contain useful observations, results, or generalizations beyond the immediate problem. These observations provide background material and may help in developing guidelines for conducting system/human operator analyses. Such reports also can serve as good examples of how to do a specific study, if the conditions and requirements are similar.

SYSTEM DEVELOPMENT PROCEDURES

A specific, "how-to" document that is the objective of this project has not yet been discovered. Excerpts from selected documents that might prove useful are given below, without the detailed definitions of terms found in some of the references. Hopefully, the gist of the statements and diagrams will suffice for the moment.

The Concept

According to the Human Engineering Guide to Equipment Design,[20] the system concept of design and development is the concept of a group of components designed to serve a given set of purposes. In the U.S. Armed Forces, a set of purposes is called a mission; in industry, the purpose might be the production of a commodity or the construction of a facility. In any case, system design is the design of a total system so that it serves its intended purposes or missions.

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[18] Sivazlian, B. D. and L. E. Stanfel, Analysis of Systems in Operations Research, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1975.

[19] Au, Tung, R. M. Shane, and L. A. Hoel, Fundamentals of Systems Engineering: Probabilistic Models, Addison-Wesley Publishing Company, Reading, Mass., 1972.

[20] Human Engineering Guide to Equipment Design, First Edition, Morgan, Cook, Chapanis, and Lund, Editors, 1963, McGraw-Hill Book Company Inc., New York.

System Design[20]

System design includes the traditional engineering of individual equipments. A set of procedures must be followed for conceiving and developing a system as a whole in such a way that each component is fashioned to make its proper contribution to the ensemble. Though it inevitably involves a certain amount of traditional "cut and try," it can be a rational, orderly process of analyzing a system, more or less quantitatively, before it exists, then designing it, and, later, evaluating the system in its prototype or preproduction form.

System Analysis[20]

System analysis gives as accurate a picture as possible of the structure and functions of a system - of the way it is to be put together and of the processes that are to go on in it. System analysis is a part of the system design process. A system analysis, when completed, is a detailed description of the components of a system and of the operating characteristics of those components, whether men or machines. It is a statement of the capabilities, limitations, and interdependencies of the components expressed in terms that are relevant to the overall mission of the system.

Procedures

Meister and Rabideau[14] list the procedures in doing a functional analysis. Both system development and system evaluation depend on the functional analysis performed in the predesign and early design phases. Functional analysis refers to the processes by which the embryo man-machine system is planned. Functional analysis attempts to allocate functions between men and machines, to describe the tasks performed by personnel and equipment, and to specify the criteria to be utilized in system design.

Functional analysis is accomplished by performing the following steps:

1. Determining the system mission requirements.
2. Profiling the system mission.
3. Segmenting the mission.
4. Identifying and describing system functions.
5. Establishing functional performance criteria.
6. Allocating functions.
7. Performing a task analysis.

Functional analysis describes the system mission, resulting in a determination of system functions and functional criteria. The human factors analysis is usually performed within the framework and as a part of an overall system analysis, with the human engineer participating as one member of a team composed primarily of engineers.

Procedure Diagrams

Procedures to be followed in the system analysis process have been diagrammed by many authors; several examples are shown in Appendix A to illustrate how different people view the process. Some are useful, some aren't. A simplified diagram that will serve as a starting point in this report is shown in Figure 2.[21] More detailed steps in the process will be given later in this report as the analysis process is developed.

In summary, this background section has intended to give the reader, (1) an idea of what a system is, and (2) the analytic processes that have been used in the development of a system.

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21 Air Force Systems Command, Measures of Effectiveness Literature Survey, by Robert A. Hermann, April 1974, DCS/Development Plans, AFSC, Kirtland AFB, NM, OAS-WP-74-2.

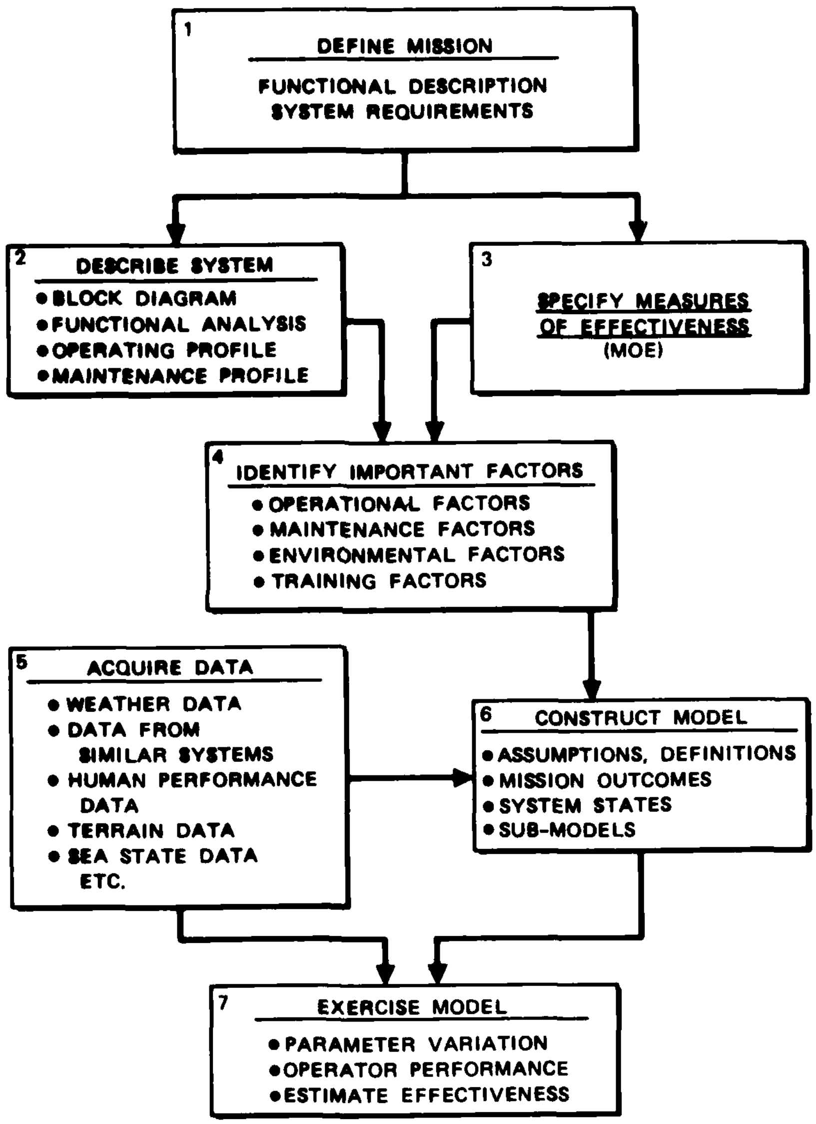

FIGURE 2. Principal Tasks Required for Evaluation of System Effectiveness (adapted from reference 21).

SYSTEM PERFORMANCE

This section of the report will discuss some concepts in systems performance, and the operator's contribution to it.

WHY PREDICT PERFORMANCE?

The best way to find out how well a system works is to measure its performance; this is usually done in a test facility (or on a range) where the necessary measuring equipment is available. The effectiveness of existing systems must be predicted, however, for conditions where there are no test data, where testing is not a feasible way to indicate performance, or where an existing system (the "baseline") is compared to a new, hypothetical system (the "improvement").

The effectiveness of hypothetical, or proposed systems is predicted to provide data for decision-making at many levels: from specification of system components (e.g., the field-of-view of an optical sensor), all the way up to deciding whether a new system should be procured at all. The characteristics of these hypothetical systems must be specified in enough detail to allow them to be modeled. The human operator's role in system operation must also be specified.

MEASURE OF EFFECTIVENESS (MOE)

The next few sections of this report will discuss the items in the boxes of Figure 2. After that will follow the specifics on how to implement Figure 2.

The products of a system effectiveness analysis are usually numbers of some sort that describe how well the system performs its functions. It is important that these numbers, or measures of effectiveness (Box 3, Figure 2) be useful to the sponsor, user, or decision maker for whom the analysis was done. A textbook or primer on developing MOEs was not found in the course of this study, and yet selecting the proper MOEs is very important in any analysis.

Example

Let us assume that a new transport system is being proposed; it would transport individuals via surface vehicle from place to place within a city. Some MOEs for this system are shown in Table 1.

Are the example MOEs in Table 1 useful to the decision makers and/or design engineers? Are they quantifiable? How can they be modeled or estimated? How many MOEs should be used?

TABLE 1. Some MOEs for a Transport System.

1. Percent of people desiring transportation at any one time that can be transported.
2. Timeliness in maintaining schedule.
3. Amount of time spent by passengers waiting for next bus.
4. Speed of transportation.
5. Accessibility of bus stops to homes, offices, etc.
6. Accident rate on transportation system.
7. Crime rate on transportation system.
8. Comfort during transportation.

Good characteristics for an MOE found in Military Operations Research Society documentation include:

a. Relevancy to the mission

b. Relevancy to the design issues

c. Relevancy to the decision-makers

d. Quantifiable

The analyst working on a problem at any level must realize his MOE may be used by another analyst working at the next higher level. Each analyst must, therefore, understand fully how his analysis will be used at levels above and below him.

There are different MOEs for the various aspects of system employment and these different MOEs must all be relevant to the success of system employment. The human factors analyst is rarely given the detailed MOEs with which he must be concerned; he must identify them himself. These MOEs should:

1. Be "approved" through a process of iteration and negotiation with the program managers and other analysts.

2. Be required in some decision process (e. g., component selection).

3. Be clearly stated in the final study report, with the rationale for selection also given.

4. Include aspects of the physical environment that affect operator and system performance.

5. Use variables that are readily measurable in the real world, and/or for which there is a data base.

6. Be useable by other analysts in the program.

Guidelines For Developing MOEs

MOEs are created for specific circumstances and must be backed up by experienced judgement. A suggested procedure for the development and application of MOEs is given by Anderson, et al,[22]:

a. Develop or create as many sensible MOEs as possible.

b. Categorize them into groups of similar measures.

c. Select the best MOEs in each group using a procedure to evaluate those that are strong or weak, or alike or similar.

d. Point the selected MOEs to the next higher level of objectives: i.e., insure that the MOEs are so constructed that they can serve as performance indicators to the next higher level.

e. Express the MOEs in standard notation of physics, engineering, and mathematics (i.e., time required, distance covered, percent defects identified).

A similar process is to specifically relate MOEs to mission objectives.

a. List important mission features, so that the MOE will have a better chance of reflecting the way a mission must be conducted in order to be effective.

b. Develop an extensive list of conceivable MOEs for the mission (no initial constraints should be put on this brainstorming).

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[22] U.S. Army Combat Developments Command, Force Developments; The Measurement of Effectiveness, by D. C. Anderson, et al, January 1973, Ft. Belvoir, VA, USACDC Pamphlet No. 71-1.

c. Reduce the list by discarding duplication and MOEs that are not in some way related to the mission objective.

d. Write a brief discussion of each of the MOEs and give the analyst's views of some of the general characteristics of each MOE.

An example of the product of the above procedure is shown in Table 2. The headings across the top of Table 2 could be used in any MOE development.

TABLE 2. General Characteristics of Candidate MOEs for Close Air Support (CAS) Mission.

Candidate MOE	Relation to mission objective	Systems that can be compared	Typical availability of data	Inherent assumptions	Ways the measure can be misleading
Reduction to overall losses to friendly forces while they are being assisted.	Direct	All	"Casualty-producing" data are required for enemy forces and enemy tactics.	. . .	In some situations, time to achieve objective may be important to coordinate multiple ground force operations.
(Our fire support X duration of support)/response time.	Implied	Those that are similar in two of the three parameters.	Fair; predictability of response time is usually suspect.	Enemy lossed produce a *corresponding* reduction in friendly casualties.* Weapons will not endanger friendly forces.	Ration allow one *parameter* to overpower others.
Response time	Implied	All	Poor; response time often depends on people and varies greatly.	Systems that provide rapid response will be able to achieve mission objectives.* Individual situations are short-term and duration of support is not too important.	Long-term benefits of slower but more lethal weapons may be overlooked.
% of time the system can be used.	Implied	All	. . .	Enemy is resourceful and will take advantage of times we cannot supply CAS.*	A low-performance weapon with all-weather capability may not reduce our losses.
Time for ground forces to achieve their objectives.	Implied	All	Very poor; there are no known data to support time estimates; also, situations vary greatly.	Casualties are directly related to time required to handle a particular situation.*	Losses incurred while achieving objectives are not necessarily examined.

*Candidate MOE is tied to the mission objective if this assumption is valid.

If more than one MOE is used, as is usually the case, a scheme must be devised for establishing relative priorities. Several MOEs can be combined with weighting factors to produce a single "summary" MOE.

In summary, the determination of the measures of effectiveness is an important early step in the analysis process. There are no set rules, but the guidelines given above are useful. The procedures in determining the MOE will be discussed in more detail later in this report.

FACTORS AFFECTING SYSTEM PERFORMANCE

The factors affecting system performance (Box 4, Figure 2) can be broken down in several ways; one such way is shown in Table 3. The operator's performance requirements are determined by the man-machine function allocation and will be discussed in more detail in the next section.

TABLE 3. Breakdown of Factors Affecting Overall System Performance, with Examples of Subdivisions.

1. Operator Performance/Capabilities
    a. Search Time
    b. Tracking Accuracy
    c. Data Entry Time
2. System Characteristics
    a. Software
    b. Hardware
    c. Capabilities
3. Operator's Environment/Operating Conditions
    a. Workload
    b. Time Available
    c. Physical Environment
4. System's Environment/Operating Conditions
    a. Weather (e.g. visibility)
    b. Communication Interference (e.g. jamming)
    c. Obstacles/Threats

    etc.

The system characteristics in Table 3 describe the system such that its capabilities can be predicted. The analyst only needs to go to the level of detail required to predict capabilities. As an example, "The engine is such that a velocity of 80 mph can be sustained for 3 hrs" is sufficient. Whether it is a gasoline or diesel engine would not be relevant to operator/system performance effectiveness estimates.

A description of the operator's environment is necessary to estimate his/her performance, and will be discussed in the next section. As an example, the time available to do the job might be related to vehicle velocity, orbit period, or conveyor belt speed. Aircraft maneuvering requirements determine the "g" level under which tasks must be performed. Vehicle vibration would affect manual tracking accuracy.

The system's environment (Item 4 in Table 3) can be different from that of the operator, and also affects system performance. Many systems are expected to function under a wide range of conditions; for example, temperatures from $-50^{\circ}F$ to $+130^{\circ}F$, humidities from 0 to 100%, and altitudes from 0 to 60,000 ft. Those conditions that affect the performance of the system must be included in the analysis. For example, the roughness of the terrain directly affects how fast a vehicle can move across it. This factor must be included in personnel carrier design studies.

Frequency of Occurrence

The distribution of the values of a factor that affects performance is used as a weighting term in the overall effectiveness calculation. These distributions are difficult to obtain in many cases; estimates rather than actual data must often be used.

As an example, assume that a system must operate in various types of terrains and weathers, and it has been established that both terrain type and visibility affect performance. Tables 4 and 5 show hypothetical distributions of anticipated employment environments. If terrain type and visibility are correlated (e.g., the desert is mostly clear), this "interaction" must also be taken into account in the weighting procedure.

The analyst must tabulate the factors (or variables) affecting system performance, specify the range of the variables (e.g., 0 to 60,000 ft), and most important, determine the distributions of values of the variables.

These variables can then be used in calculating performance; a common result would be the percent of the time that the system could be used, or the parts of the world, or percent of terrains where its employment would be satisfactory. These items are essentially the MOEs that have been determined earlier in the analysis.

TABLE 4. Hypothetical Terrain Distribution for Anticipated Employment of System.

Terrain	Percent Use
Flat Desert (sand)	5
Flat, Open Farmland	25
Flat Forests	25
Forested Mountain	20
Open, Snow-covered	20
Other	5
Total	100

TABLE 5. Hypothetical Visibility Distribution for Anticipated Employment of System.

Visibility Interval (stat. miles)	Percent Occurrence
0 - 3	20
3 - 6	40
6 - 9	30
9	10
Total	100

PREDICTING/ESTIMATING SYSTEM COMPONENT PERFORMANCE

The following two sections deal with how to get data about the system and its environment (Box 5, Figure 2).

Figure 3 illustrates four concepts of how component performance has been quantified by different analysts. In (A), the simplest, a given input (e.g., light) makes it possible for the component to produce an output (e.g., a photograph).

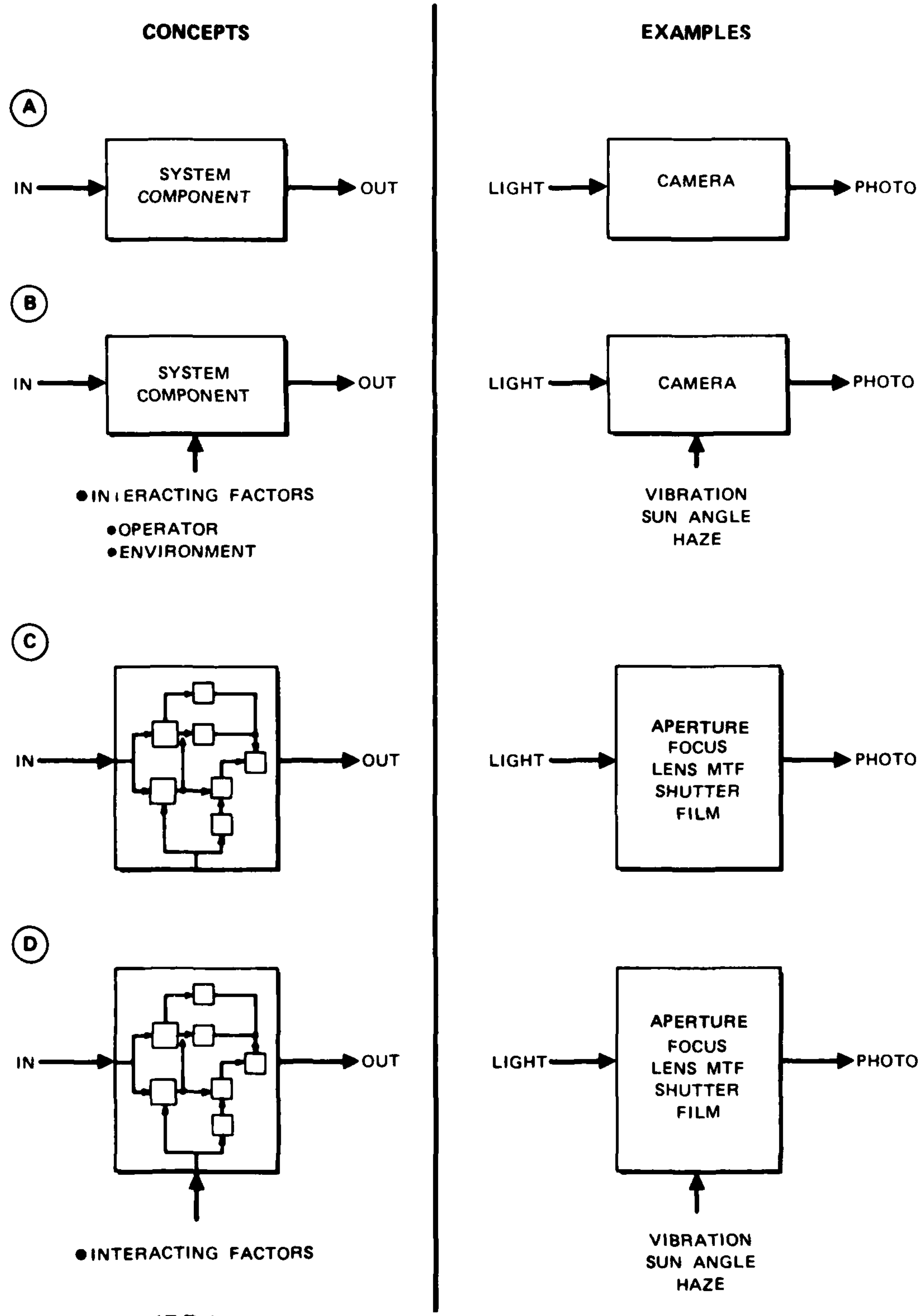


FIGURE 3. Concepts in Describing Component Performance.

In concept B, interacting factors are included and affect the output. In the operation of a camera, the operator's steadiness, and the sun angle or haze condition would affect the output. In concept C, the internal operation of the component (e.g., automatic light meter) is considered in estimating the output. If one is attempting to estimate the effect of the internal workings of the component upon system performance, then concept C is useful.

In concept D, the interacting factors are added. Concept D would produce the best estimate of performance, if it can be implemented properly. Concept B includes the system aspects of performance and would be the second choice.

Several methods of getting estimates of component performance can be used: mathematical models, laboratory measurements, simulations, and measurements made in the real world. These methods overlap, and sometimes compliment one another. There are no standard definitions of the terms, but the point to be made is that there is a continuum of estimation methods.

An example of this continuum and its application to Figure 3 is shown in Table 6, which contains subjective estimates from two people with experience in target acquisition systems. The entries could well change for other functions performed by other types of systems.

TABLE 6. An Example of the Usefulness of Methods of Estimating Performance.

Method of Predicting Performance	Component Performance Concept			
	A	B	C	D
Math Models*	Poor	Medium	Good	Medium
Laboratory Measurement	Good	Medium	Good	Medium
Man-in-the-Loop Simulation	Poor	Good	Poor	Good
Field Trials	Poor	Good	Poor	Medium
Operational Performance	Poor	Medium	Poor	Poor

* or computer simulation methods

The observations that can be made about Figure 3 and Table 6 are:

1. Concepts A and B are empirical. We don't know what's inside each box, and hence can't model it. We don't know how interacting factors will change the output in concept B because we can't "model" how it operates on its inputs. We can only measure the output.

2. The use of Concepts A and C in simulation, field testing, or operational data collection does not produce the data one usually desires, since the concepts do not include "outside", interacting factors.

In summary, estimating component performance can treat the component as a "black box," or consider its internal make-up. If interacting factors such as the operator or the outside environment have a strong influence upon the component's performance, they should be included.

There are many ways that this performance estimation can be made, ranging from math models to field tests. The selection of both concept and method is a subjective process influenced by time, cost, and accuracy requirements, but it is a process that should be consciously carried out and documented. Information like that contained in Figure 3 and Table 6 can help the analyst chose the proper approach. He should build his own Table 6 with inputs from experts on his particular application.

HUMAN OPERATOR PERFORMANCE

The operator's performance at the different tasks required in system operation must also be measured or estimated. The data are represented in Boxes 5 and 6 of Figure 2.

The concepts of measurement of the performance of the human operator are similar to those shown in Figure 3 and are shown in Figure 4. A task description, or instructions to the operator, is shown as the input. The operator performs the task using, in some way, the system component(s). This could be a display (target recognition), a control stick and display (tracking), or a steering wheel, clutch, gear shift, brake, etc. (driving). The man/machine combination can be considered as a unit, as separate units, or each as a number of sub-components.

Performance can be estimated with or without consideration of environmental factors. In addition, the operation of a system usually involves many tasks with different system components, so many such boxes would be required to represent system operation. For example, aircraft flight involves "steering" the aircraft, operating the flight system, the radar system, and the navigation system, as well as communicating.

There are other important factors not shown in Figure 4: operator training, skill level, and motivation. Levels of these factors should be specified when appropriate (and possible). They are considered to be part of the operator in Figure 4 and are not shown separately.

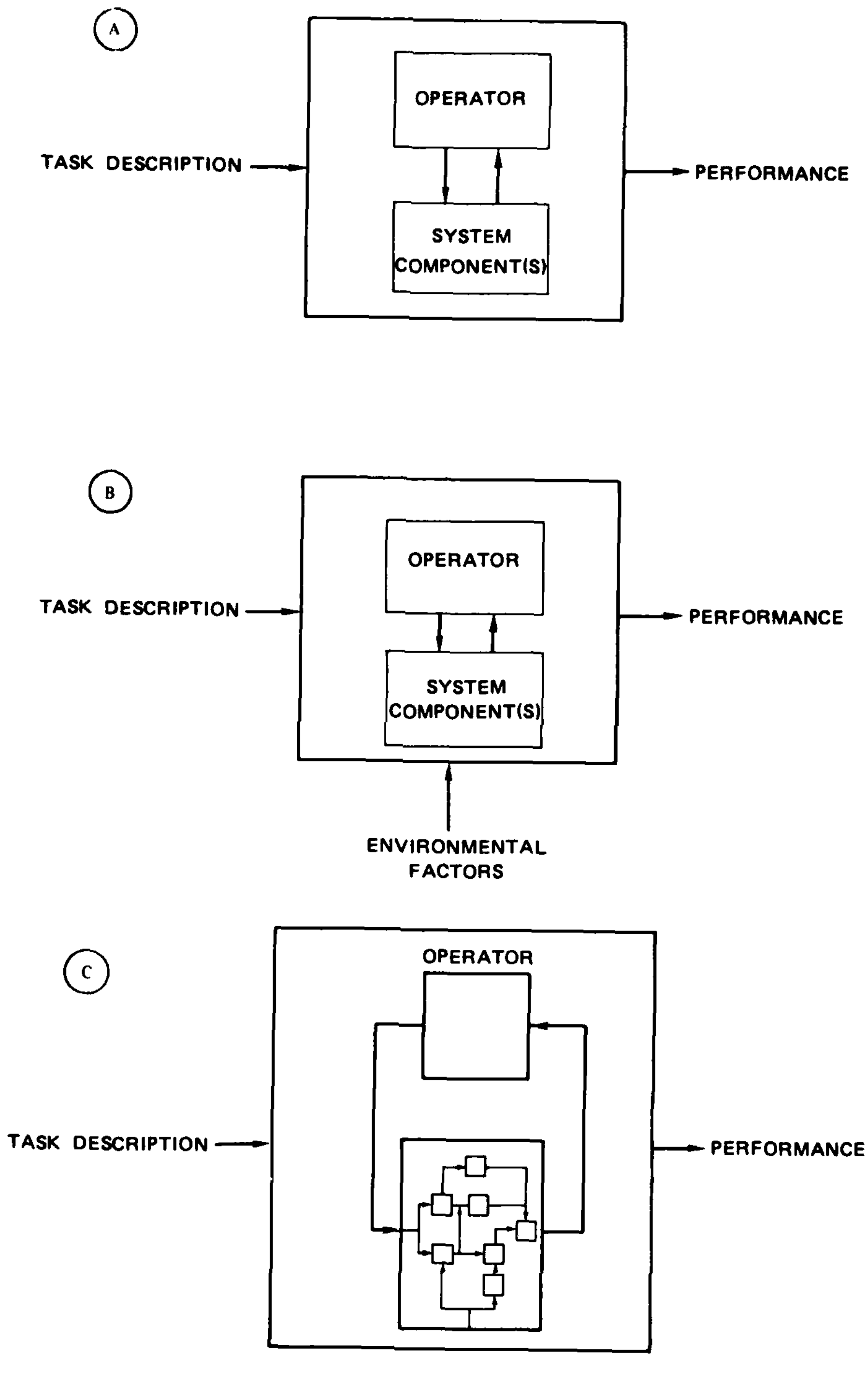
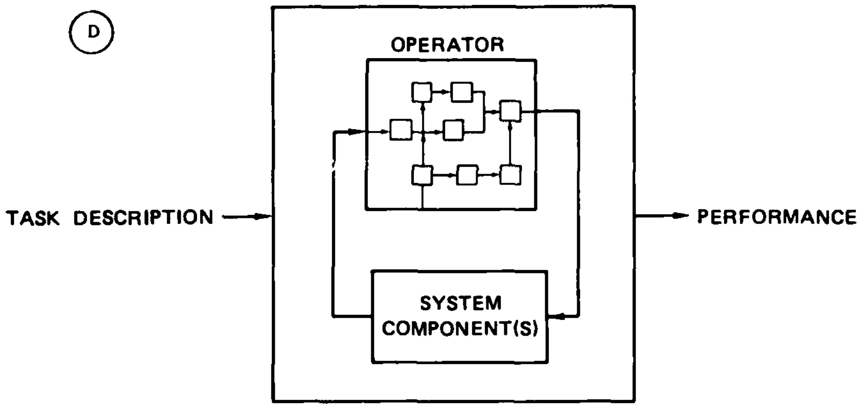
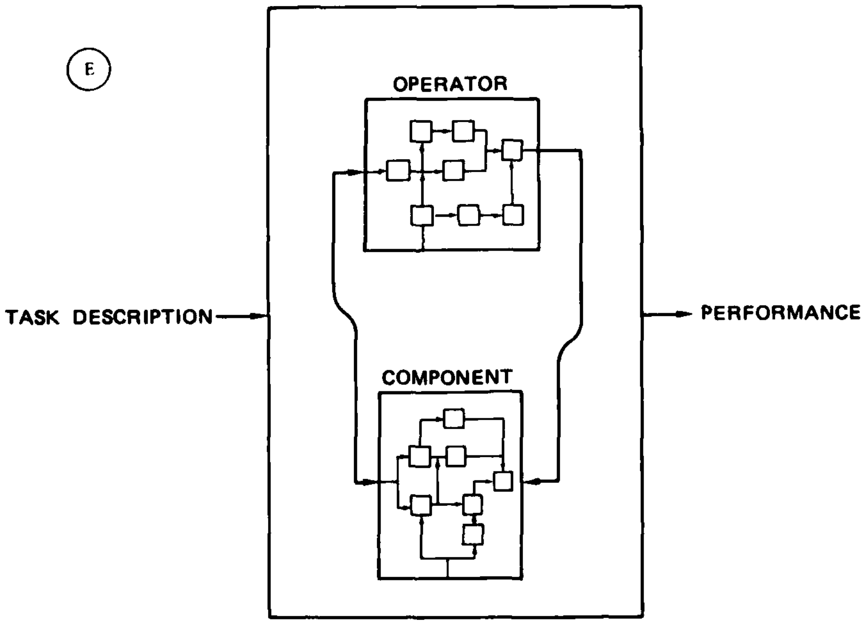


FIGURE 4. Operator Performance Concepts.

D



E



F G, OR H

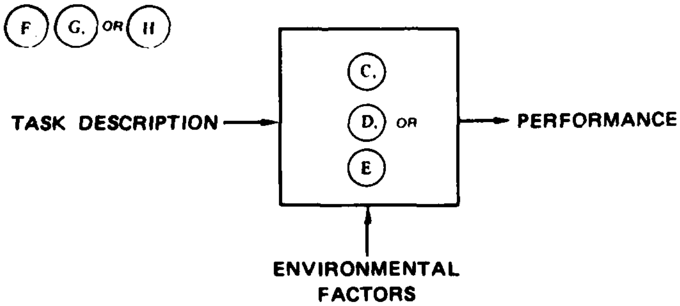


FIGURE 4. Operator Performance Concepts (Contd).

Some personnel stereotypes could be associated with the boxes in Figure 4, although as with all stereotypes, the association is not accurate all the time, and is sometimes unjust. The "academic" analyst sometimes uses Figure 4A. The experienced, "real-world" analyst uses 4B, since he is aware that environmental factors can be very important. Some engineers prefer 4C; they like to tinker with the hardware. Psychologists like 4D where human modeling is stressed, and mathematical modelers and programmers prefer 4E or H since everything in the world can be modeled!

DESCRIBING THE TASKS

Before operator performance data can be found or generated, the tasks, system components, and important environmental factors must be described (Boxes 2 and 4, Figure 2). A number of human factors techniques that can be used are well documented by Meister,[13,23] by Coburn,[24] and in The Human Engineering Guide to Equipment Design.[25]

The task description used in system effectiveness studies for simple tasks need not be as detailed as is required for specific equipment design studies. For example, the shape, size, or kind of control (button or switch) need not be specified. It can be assumed that the most appropriate control will be selected by later human factors design studies. An estimate of the distribution of times required to operate the control may be the only description required, for instance.

Complex tasks, which are often affected more by outside influences (e.g., the weather) need to be described in more detail to make sure that the performance data used in the analysis is appropriate.

OUTSIDE FACTORS AFFECTING TASK PERFORMANCE

Both Figures 3 and 4 show interacting or environmental factors in some concepts as inputs which affect performance. These outside factors need not be considered part of the system, and are usually not. But they <u>must</u> be included when it comes to estimating performance.

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[23] Meister, David, <u>Human Factors: Theory and Practice</u>, John Wiley and Sons, Inc., New York, 1971.

[24] Naval Electronics Laboratory Center, <u>Human Engineering Guide to Ship System Development</u>, by R. Coburn, 3 October 1973, NELC/TD 278, San Diego, CA.

[25] <u>Human Engineering Guide to Equipment Design</u>, edited by H. P. Van Cott and R. G. Kinkade, Superintendent of Documents, 2nd Edition, U. S. Government, 1972.

Factors affecting performance are represented by Box 4 in Figure 2. They can be divided into three categories, with the inevitable overlap one finds with any such taxonomy. System characteristics are those things that the engineer can solder, measure, program, polish, or pound on. Operating conditions indicate how the system or subsystem will be used, and environmental factors describe where or when it will be used. Examples of these categories are given in Table 7. A list similar to Table 7 should be made up in the initial stages of the analysis.

Interrelationships or independence of these factors must also be considered. Some factors will affect the equipment operation independent of the operator (e.g., haze will reduce the quality of a photograph), and others primarily will affect the operator's ability to perform (noise or ambient temperature in the workspace). There are also factors which can affect both equipment and operator (vibration).

It is important to include these factors in the task description so that the search for or generation of data will produce a good estimate of performance. The human factors literature and handbooks (reference 29) list most such factors and give some idea of how they have affected performance in the past. A few examples are given in Table 8.

OPERATOR CHARACTERISTICS

Figure 4D and E show the operator as something that could be described or modeled. Many operator models have been developed and can be used when appropriate (e.g. manual tracking or visual performance). Factors such as skill level, pertinent experience, fatigue, training, and motivation are important; if they can be defined and quantified, they should be included in the analysis. At the very least, assumptions as to these factors should be stated in the analysis documentation.

TABLE 7. Examples of Outside Factors Affecting Operator Performance.

System Characteristics

- Audio Tone Characteristics (Frequency, Volume)
- Display Size and Viewing Distance
- Display Format (Symbols, Color)
- Field-of-View of Optics or Windows
- Sensor Characteristics (Resolution)
- Steering Control Size and Configuration
- Slew Controller Size and Shape
- Tracking Loop Design (Rate-Aided)
- Workspace Layout

Operating Conditions/Requirements

- Vehicle or Aircraft Velocity
- Altitude of Flight or Depth Under Water
- Accelerations to be Encountered
- Time Available to Perform Task(s)
- Task or Mission Duration
- Distance to be Traversed

Environmental Factors

- Wind Velocity
- Air Turbulence
- Temperature, Humidity
- Outdoor Light Level (Day, Night)
- Visibility or Atmospheric Transmission
- Terrain Roughness
- Water Roughness (Sea State)
- Slickness of Driving Surface
- Traffic Density
- Electronic Jamming

TABLE 8. Examples of Operator Tasks and Outside Factors That Can Affect Performance.

Task	Outside Factors
Visual Perception	Visibility
Detecting	Occluding Objects
Reading	Vibration
Identifying	Acceleration
Searching	Camouflage
Manual Tracking	Vibration
	Acceleration
	Visibility
Aural/Oral Communication	Vibration
	Acceleration
	Background Noise
	Jamming
Decision-Making	Number of alternatives
	Value or utility of each alternative
All of the Above	Training/Experience
	Expectation
	Consequence of Error
	Motivation
	Time Available
	Workload
	Mission Duration

THE FORM OF PERFORMANCE DATA

THE RAW DATA

Human operator performance data used in analysis has taken many forms: average, mean, or median scores, frequency distributions, and cumulative plots. The raw data generated by field tests, simulations, or laboratory experiments can take the form shown in Figure 5. This data form implies that:

1. a given test condition has been repeated a number of times,
2. a number of different operators have been used in the tests,
3. or, the same operator was used in a number of test trials.

It should be stressed here that the data shown in Figure 5 is typical. There is always a distribution in scores, not just one value. This distribution, or variability, is caused by differences between people, or within the same person at different times. Other causes can contribute to the variability that we cannot control, identify, or measure. Suffice it to say that a distribution in performance scores is a natural phenomenon, and we must take it into account in our analysis or we will get spurious answers.

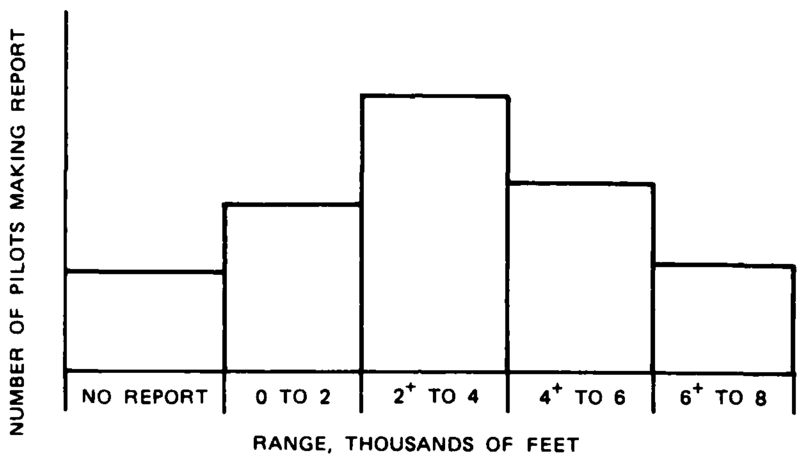

FIGURE 5. Distribution of the Range at Which an Aircraft is Sighted for a Specific Environmental Situation.

Figure 6 shows the same data plotted in cumulative form. The curve in Figure 6 represents performance under one set of conditions. A large number of such curves would be produced in an experiment where several parameters were varied.

THE TRADITIONAL DATA

Many curves similar to the one in Figure 6 are usually summarized by picking one point off of each curve (the dotted line in Figure 6) to use as an indicator of performance. The rationale for this is given by Taylor:[26]

> "It is found, upon plotting many hundreds of such stimulus presentations, that the probability of target detection rises with stimulus magnitude in accordance with an ogive curve

[26] Taylor, John H. "Use of Visual Performance Data in Visibility Prediction," Applied Optics 1964, Vol. 3, No. 5, p. 562.

which is well fitted by a normal Gaussian integral. Statistically, the best determined point of the ogive is the point of inflection, i.e., where the probability of correct discrimination is 0.50, and this is the value of threshold contrast of prime interest in laboratory studies."

The above procedure is standard in well controlled laboratory studies, and analysts often use such averages, means, or medians computed from raw data. The analyst should not use such averages in system effectiveness analysis, however; the result can be very misleading. If a median is used as the performance data, 50% of the operators may do better than required by the design; but 50% will do worse. Hence, the system may be optimized for only the best half of the operators! Data, in the form shown in Figure 6, must be used. The problem is to find such relatively complete data from past experiments or tests.

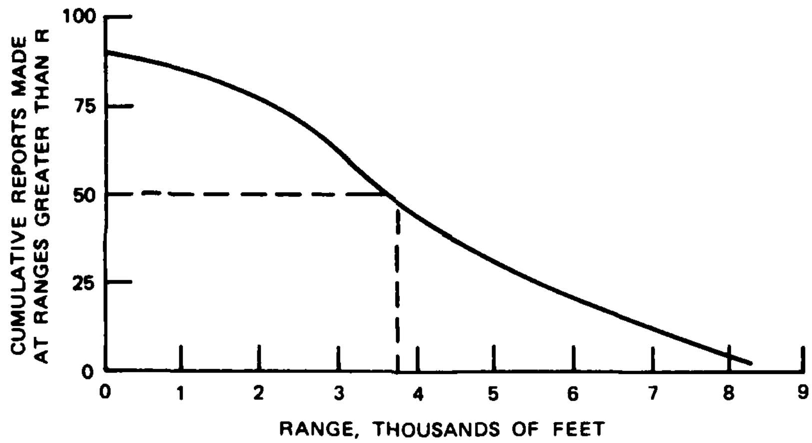

FIGURE 6. Normalized Cumulative Plot of the Distribution in Sighting Ranges Shown in Figure 15. This figure is usually called the cumulative percentage of detection range.

OBTAINING PERFORMANCE ESTIMATES

The analyst would like to obtain the operator performance estimates without having to generate them himself.

Estimates can be obtained from theoretical studies, computer simulation models, laboratory experiments, man-in-the-loop simulations, or field tests. Figure 7 shows such a continuum, with finer divisions in the procedures than are shown in Table 6.

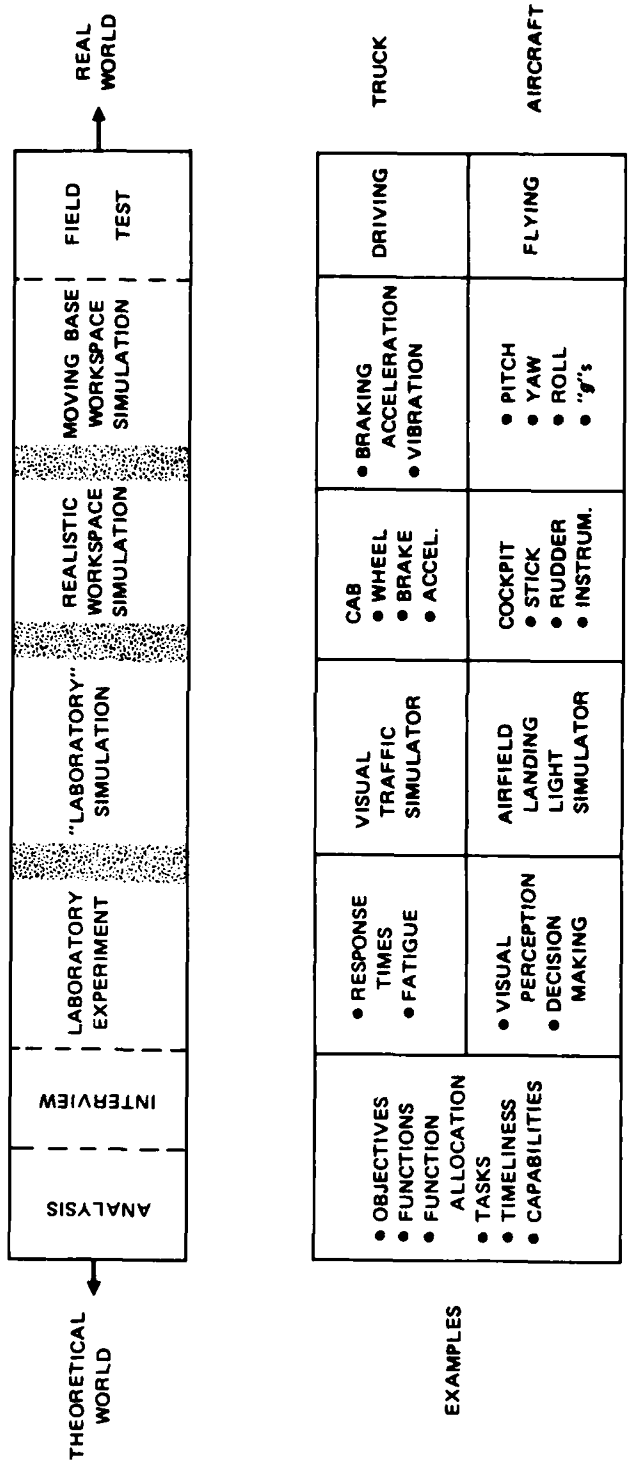

FIGURE 7. Example of Data Sources for Truck and Aircraft Design Studies.

Although the terms "estimates" and "data" are used interchangeably here, the purist might argue that theory and models produce calculations and experiments and field test produce "real data"!

The quality or applicability of the estimates varies according to the source and the system or tasks in question. In other words, each different technical area will have its own source of information for use in estimating performance; some technical areas have more and better data than others.

Table 9 shows an example of an evaluation of data quality for a specific application. Such a table can be made for any technical area by those working in the particular field and used as a guide in planning analysis and validation tests.

TABLE 9. Example of Operator Tasks and Performance Measures, and "Best Bet" Data Sources for a Target Acquisition System.

Operator Tasks/ Performance	Analysis	Laboratory Experiments	Simulations	Flight Tests
Weapon Delivery Accuracy	X			X
Target Detection	X	X	X	X
Target Classification		X	X	
Target Identification		X	X	
Range at Detection (D) Classification (C) Identification (I)			X	X
Time to Operate System			X	X
Time to D/C/I		X	X	
False D/C/I		X	X	

Data must be selected by somehow balancing applicability and validity. The best source is tests done expressly for the analysis being performed. The second source would be data from tests or simulations dealing with a similar system. Multiple sources can also be used (including interviews with experienced operators); if a consensus emerges, so much the better. Selection of data is a subjective process where experience both in analysis and in conducting human factors experiments helps. It is important that the data sources be documented, so that the results can be explained to reviewers of the analysis, and so that additional data can be comprehensively included at a later date.

DEVELOPING A SYSTEM EFFECTIVENESS ALGORITHM

ITERATIONS REQUIRED

Two types of iterations are required throughout this analysis; personnel iterations and technical iterations. The participants in a system development effort are listed in Table 10; discussions among some of these participants is a requirement at various stages of the analysis process. Agreement or approval with what has been produced is the goal of these discussions. The discussions will result in changing some of the analysis: the iteration process.

Some of the iteration points will be identified below. Others are of a non-technical nature and will not be included in this report.

OVERVIEW DESCRIPTION

The procedures in conducting the analysis have already been described in general above. The first step is to document the mission and system concepts that would be found in Boxes 1 and 2 of Figure 2. This Overview Description is based upon work that has presumably already been done but sometimes is not adequately documented.

Doing that initial work (i.e., determination of requirements; system concept formulation) is not the subject of this report; it is assumed here that the work has been done, and must be documented in a form suitable to the analytic process.

Table 11 shows the first steps in describing the situation. Items in the table can be related to previous sections of this report, and have already been discussed at length.

The design of a bus for public transportation will be used as an example throughout the remainder of this report. An example such as a fighter or attack aircraft or a weapons system was intentionally not used in this study. It was felt that using something that the author has not worked with before would produce a better generalization of the techniques. Table 12 shows the application of Table 11 to the design of the transport system; it is not meant to be complete in itself, but only to bring Table 11 into the real world.

TABLE 10. Example of the Participants in the System Effectiveness Analysis Process.

Participants	Example of Specialty	Remarks
1. Analysts	Operations Research Systems Analysis Human Factors	Members of the concept, design, and evaluation team.
2. Engineers	Mechanical Electronic Optical Aeronautical Human Factors	Principal members of the design team.
3. Scientists	Atmospheric Oceanographic Psychology Physics Chemistry Mathematicians Computer Scientists	Usually consultants.
4. Current Users	Pilot Fireman Truck Driver Farm Worker	May not be near design team. Also, they may not understand the design process.
5. Managers	Branch Chief Project Head Program Manager Team Leader	Coordinate and direct work.
6. The Principal Design Team Members	Managers Analysts Engineers User Representatives	Should be a cohesive group each with designated areas/responsibilities.
7. Sponsors	Higher Level Manager Former User	Can be regarded as customer, but may not be the actual user.
8. Administration	Budget Procurement	May only be concerned with procurement, schedules, and the budget process.

TABLE 11. Steps to be Taken in Producing an Overview Description.

1. Define and Document the Objective.

2. Define and Document Special Requirements.

3. Define and Document the System (broken into Major System Components).

4. Define and Document the Operator(s) Characteristics.

5. Identify and Document the Operating Times, Places, and Environmental Conditions (see Table 3).

6. Identify and Document Other Factors or Entities Affecting System Operation, (See Table 3).

7. Describe and Document the Operating Concepts.

   a. How will the system be used?

   b. What role do major system components play?

8. Determine General System Measures of Effectiveness.

TABLE 12. Brief Example of an Overview Description for a Transport System.

1. Objective: Transport people (the public) via surface bus from place to place within a city.

2. Special Requirements: The system should have the capability of transporting individuals on foot, individuals with their bicycles, individuals on crutches and canes, and individuals in wheel chairs. Pets need not be transported.

3. Major Components: The basic system is considered to be:

   a. The bus (vehicle) and accessories (e.g., loading ramp)
   b. The driver
   c. The conductor/subsystem operator (if required)
   d. A centralized dispatcher
   e. The communications system between bus and dispatcher.

4. Operator Characteristics: The operator characteristics (driver/conductor) are:

   a. Adult male or female
   b. 90 percent of general population with respect to height, weight, strength characteristics
   c. Possesses chauffeur's driving license for bus-type vehicles.

5. Operating Conditions:

   a. 24 hrs per day, 7 days per week
   b. Anywhere within city limits, including on freeways (alleys and such narrow passageways excepted).
   c. Operation is required in snow, rain, fog (restricted visibility), daylight, dark; dry and wet or snow/ice-covered pavements are included.
   d. Operation must also be in light to heavy city traffic; maximum street slope is 5% grade.

6. Other Factor/Entities: Other similar vehicles will be performing same or parallel functions; street signs, traffic regulations, controls, and advisories; passenger characteristics and density; type/shape of bus route.

7. Operating Concepts: Passengers will be picked up and dropped off at designated locations; some schedule that passengers will know ahead of time will be established. Bus accessories will load passengers; bus will transport passengers; other operating concepts should be determined without necessarily using traditional methods.

8. MOE: Percent of passengers desiring transport that can be transported in normal and peak hours; timeliness in keeping schedule; accident rate; customer satisfaction (see Table 1).

First Review

When the overview description (Table 11) is complete, it should be reviewed by two groups shown in Table 10: #6, principal design team members and #7, sponsors. Understanding and approval by these two groups will help insure: (1) that everyone will be working to the same goals within the same framework, and (2) that the customer will get what he thinks he is buying.

The analysts circulating the overview description must expect that changes will be made in it. The changes may even be improvements in some cases! It is rare that changes will not be made (at a minimum, wording or preferential editing).

Second Review

The changed Overview Description should next be reviewed by a few current users of a similar system (#4 in Table 10). The analyst should present to, talk with, or interview bus drivers, pilots, control tower operators, customers, or whoever is appropriate. Do the concepts in the description make sense in light of their experience? Was anything left out?

It must be kept in mind that many users are not familiar with the design process, or with advanced concepts in technology. The presentation of material to be reviewed should orient them toward thinking about an advanced system. Their comments must be interpreted in this light also.

SYSTEM DESCRIPTION

Hardware/Software

The system must now be described in more detail, with major components that are thought to relate to effectiveness clearly identified. The completeness of the description will be related to the stage of design/development and to the conventionality of the system. The newer system will have a more complicated description since alternate components and configurations will have to be included. Table 13 lists the steps to be taken in this system description.

Table 14 shows a partial description of the vehicle of the transport system described earlier. Table 14 is only an example, but it does indicate that some mission requirements and real world constraints will lead to an initial set of numbers. Some numbers may be engineers' first guesses that are given to the human factors engineer or analyst. The numbers can be a first iteration in the design process and as such are "negotiable." Other items like the communications sub-system would have to be described in a similiar way.

TABLE 13. Steps in System Description.

1. Use information describing the system that already exists.

2. Include only those components that are thought to relate to overall system effectiveness. Keep this first description general; don't describe the detailed parts of a component.

3. Identify design decisions yet to be made on specific components. That is, indicate which components are still selectable, and indicate the range in characteristics that is still possible.

4. Include alternative configurations if a specific one has not yet been adopted.

5. Have the system description reviewed by the design team.

TABLE 14. Bus Description.

1. Inside Dimensions: 7 feet wide by 7 feet high by 25 feet long.

2. Maximum Outside Dimensions: 8 feet wide by 29 feet long.

3. Will contain 28 to 36 seats in normal configuration; exact number to be determined (TBD).

4. Will contain 2 to 4 spaces for wheelchairs; exact number TBD.

5. Will contain 2 to 4 seats for handicapped/disabled; exact number TBD.

6. Will have two or three loading/unloading doors. Door location will be right front and right side of bus. Seat/space layout TBD, but will be compatible with doors.

7. Vehicle will use standard bus wheels and tires with minimum vertical clearance of 1 foot between tires.

8. Will have mechanism for conveniently loading/unloading wheelchairs/ handicapped, operable by driver. Mechanism type TBD (ramp, lift). The time required to load/unload 1 wheelchair is estimated by engineers to be 45 to 90 seconds.

9. Vehicle can be driven up to 65 mph.

10. Vehicle will have 3 rear-view mirrors for driver, and can have 1 TV monitor with up to 2 selectable cameras inside or outside, if required.

Table 14 contains items that may not be directly relevant to the effectiveness analysis (e.g. clearance), and items yet to be determined (TBD). To follow the steps in Table 13, the analysts or design engineers must propose alternate configurations accounting for the items TBD. One could hypothesize at least 8 reasonable configurations from the data given in Table 14.

Third Review

If these configurations are suggested by the analysts, they must be reviewed by the managers and design team members for acceptability at this point in the design process. This review process is the third iteration of clarifying assumed system characteristics.

Mission Description

The functions that must be performed with the system must be described for one complete assignment, or mission. If the system will be used on different kinds of missions, each should be described. If different configurations require different functions, they must be included also.

Standard human factors analysis techniques include function and task description, operation sequences, and construction of mission profiles and timelines.[23,24,25,27,28] If this work is complete, it can be used by the analysts; if not, they must do at least the top level (more general) work themselves. A good deal of other human factors work like workspace layout and seat design is also required, but need not be included in this type of analysis. An excellent illustration of this other work (on our bus example) was discovered in a London bookshop after this report was written.[29]

Table 15 gives some comments on this mission description process, and Table 16 shows a very brief listing using our bus example.

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[27] Air Force Systems Command. Human Engineering Procedures Guide, by Charles W. Geer, Boeing Aerospace Company, September 1981, AFAMRL-TR-81-35, Wright-Patterson Air Force Base, Ohio (UNCLASSIFIED).

[28] Naval Air Systems Command, System Design Handbook for Advanced Patrol Aircraft, (NAVAIR 03PA2), July 1973, prepared under contract N00019-71-C-0545. (Boeing Aerospace Company, Seattle, Report No. D180-15045-1, publication UNCLASSIFIED).

[29] Brooks, B. M., "Bus Design: A Study of Passenger Capabilities and Requirements," in Design for Work and Use: Case Studies in Ergonomics Practice, Volume 2, edited by H. G. Maule and J. S. Weiner, 1981, Taylor and Francis Ltd, London.

TABLE 15. Notes on Mission Description.

1. List and briefly describe functions that must be performed to accomplish the mission.

2. List and briefly describe the major tasks required in each function. A function and task allocation is implied here. It should have been done elsewhere as part of the human factors work on the program. It may have been done implicitly by the design engineers.

3. Do the above (1 and 2) for each configuration and mission, or show branches in the appropriate mission segments to include the alternatives.

4. Construct mission profiles for illustrating the concepts to reviewers. Those for aircraft missions sometimes show the flight path plotted by altitude and ground-track with functions or tasks indicated. Others can show a timeline, with the function or tasks shown in the proper sequence.

5. Note assumptions, alternatives, questions, or issues that come up in doing this work. This side information may prove helpful later, or must be resolved if controversial. A systematic procedure should be established to keep a record of changes in the missions as the development of the system progresses.

6. Have completed missions reviewed by design team and users.

TABLE 16. Functions and Tasks for Bus System.

Function	Tasks
1. Preparation	a. Check Oil, Tires, Battery Charger
	b. Check Brakes, Windshield Wipers
	c. Check Doors and Handicapped Loader(s)*
	d. Check Vehicle Lights
	e. Fill Fuel Tank
	f. Get Route Assignment
2. Transport Bus to First Bus Stop	a. Monitor Engine Instruments
	b. Monitor Traffic
	c. Drive Bus
3. Load Passengers	a. Park at Bus Stop
	b. Open Door(s)
	c. Operate Loader(s) For Handicapped
	d. Load Bicycles
	e. Load Other Passengers
	f. Sell Tickets/Collect Fares
	g. Close Door(s)
	h. Secure Loader(s)
	i. Check Other Passengers' Positions
4. Transport Passengers to Next Bus Stop	a. Monitor Engine Instruments
	b. Monitor Traffic
	c. Drive Bus
	d. Monitor Passengers
	e. Answer Passengers' Questions
	f. Communicate with Dispatcher as required.
5. Unload Passengers	a. Park at Bus Stop
	b. Open Doors
	c. Unload Passengers
	d. Operate Loader(s) (to unload)
	e. Unload Bicycles
6. Load Passengers	a. Operate Loader(s)
	b. Load Bicycles
	c. Load Passengers
	d. Sell Tickets/Collect Fares
	e. Close Doors
	f. Secure Loader(s)
	g. Check Passengers' Positions

* Loader/Unloader Device for Handicapped Passengers

Operating Conditions

A more complete description of the operating and/or environmental conditions than that given in item #5, Table 12 will be required. The analysts should list the conditions for both operators and machines. Guidelines such as Tables 7 and 8 should be used; a brief example is shown in Table 17.

This tabulation should be reviewed by some members of the users group. Is the tabulation accurate? Have some items been omitted? Additional insight can be gained by attaching a questionnaire to Table 17, asking for relative difficulty ratings.

TABLE 17. Some Operating Conditions for Bus Example.

Condition	Effect on Performance
1. Street Surface	
a. Dry, good repair	a. Nominal case
b. Wet	b. Slows bus/traffic
c. Icy/snowy	c. Slows bus/traffic Slows loading/unloading
d. Under repair	d. Slows bus/traffic
2. Weather	
a. Dry, calm	a. Nominal case
b. Rain, snow	b. Slows bus/traffic Restricts visibility Slows loading/unloading Slows fare collection
c. Wind	c. Could change fuel consumption
d. High or low temperatures	d. Could change fuel consumption
3. Traffic Density (Time of Day)	
a. Daytime, non-rush hour	a. Nominal case
b. Rush hours 7-9, 4-6 weekdays	b. Slows driving Increases number of passengers
c. Nighttime	c. Faster loading/unloading than nominal case Slower driving than nominal case
d. Weekends	d. Similar to nominal case
4. Passenger Density	Assumed same as above
5. Street Slope (Grade)	
a. Flat	a. Nominal case
b. Hilly	b. Slows driving

Measures of Effectiveness

Measures of effectiveness can now be generated using the descriptions of the system and missions. Guidelines in the previous MOE section and Appendix B will be helpful. The MOEs should be chosen so that they can be used in answering questions or making trade-offs that always come up in the design decision process. Hence, they should be related to the system description (Table 14). Some MOEs may have already been suggested by design engineers before the analysis was begun. The MOEs also should be related to the functions and tasks (Table 15 and 16). Two example MOEs are shown in Table 18 with some amplifying (or complicating) comments. These MOEs will have to be described in more detail, quantitatively, later in the analysis process. More about that later.

TABLE 18. Two Possible MOEs for Bus Example.

1. Timeliness in maintaining schedule along route.
   a. Routes must be defined.
   b. Schedules must be defined.
   c. Routes and schedules could be varied with time of day or week (this is a study in itself).
   d. Number of busses assigned to one route as a function of time of day or week will affect timeliness.
2. Percent of people desiring transportation at any one time that can be transported.
   a. Percent can be affected by choice of route, schedule, and number of busses assigned to a route.
   b. Data is required on number of passengers that can stand on bus if seats not available. This may also be a policy decision.

Fourth Review

At this point in the analysis, Boxes 1 through 4 in Figure 2 have been addressed. The analysts have assembled the necessary background information and are ready to start construction of an algorithm for calculating system effectiveness. It would be wise to have this baseline information approved by the program managers, principal design team members, and also by the sponsors if possible. It is necessary to get agreement that, (1) this is the system, (2) this is how it will be used, and (3) this is how it will be judged.

Action Items

A number of comments and questions will have occurred to the analysts throughout the description process (e.g. item 5 in Table 15). These should be formally recorded and included in the planning and analysis. The items can be grouped by their nature; some from the bus example are shown in Table 19.

The nature of these items depends upon the stage at which the analysis is performed. If one is estimating the effectiveness of a proposed, or hypothetical system, many questions concerning system characteristics will come up. These will have already been answered for an existing system.

MODELING THE SYSTEM

Functions/Tasks To Be Modeled

Only those functions, tasks, and components need to be modeled that affect system performance and effectiveness. All functions, tasks, and components are essential to the system (or they wouldn't be there), but some can be assumed to pose no problem in system operation.

The listing of functions and tasks (Table 16 in our example) can be used to determine what should be modeled. The steps to be taken are shown in Table 20 with brief examples from the bus design shown in Tables 21 and 22.

Column B of Table 22 in the example would be expanded to more detail in an actual analysis. That expanded description will be used as a basis for performance modeling. A brief example is shown in Table 23.

Conditions To Be Modeled or Described

The conditions to be modeled or described are also indicated in Tables 22 and 23. The type of specific descriptions must be related to the use of the data in the model or algorithm, and will be discussed later in this report.

Quantification of MOEs

The next task is to quantify the MOEs, being very specific, such that they are related to the mission (functions and tasks), the system being designed (equipment components) and the conditions of operation. A MOE may be a single item, but it is usually made up of a number of components. For example, the time required to load a bicycle may be made up of the time required to (1) open the rack, (2) lift the bicycle onto the rack, and (3) close the rack.

TABLE 19. Action Items/Notes.

1. Items To Be Determined (TBDs)

   a. Number of doors in bus
   b. Number of wheelchair spaces
   c. Number of handicapped seating spaces
   d. Number of regular passenger spaces
   e. Number of passengers allowed to stand
   f. Number of bicycle spaces available.

2. Supporting Analysis Required

   a. Generate feasible alternate configurations
   b. Conduct man/machine function allocation
   c. Conduct seat/space/door layouts to validate feasibility of configurations
   d. Generate representative routes
   e. Generate representative (nominal) schedule.

3. Data Required

   a. Traffic flow (speed) versus driving conditions and time of day
   b. Bus speeds versus driving conditions and street conditions
   c. Operating times of loader/unloader
   d. Loading/unloading times of bicycles
   e. Loading/unloading times of pedestrians
   f. Number of people desiring transportation as a function of time of day and week.

4. Bothersome Questions

   a. How can we address the interactions between route, timeliness, time-of-day, and number of busses assigned?
   b. Must we do a complete queueing study which would include various bus configurations?
   c. How do we establish "representative" routes and schedules?

5. Assumptions Made

   a. Human factors techniques will be used to produce bus layout (seats, doors, spaces), as given in reference 29.
   b. Human factors techniques will be used to determine passenger flow through bus and fare collection options.
   c. Only driver is included in effectiveness analysis at this point; if conductor is required by (a) and (b) above, provision will be made later in the anlaysis.

TABLE 20. Steps in Selecting Items to be Modeled.

1. Augment the list of functions and tasks with comments, remarks, or observations to provide a more complete description of the items.

2. Estimate the strength of the effect on the MOEs of each of the tasks. Include secondary effects.

3. Indicate which tasks are affected by the operating conditions listed earlier. Pair up specific tasks with the specific operating conditions.

4. Make a preliminary decision as to what parts of the system and system operation should be modeled.

5. Document the above.

TABLE 21. Comments on Functions and Tasks (see item #1, Table 20).

FUNCTIONS & TASKS	COMMENTS
1. Preparation	
a. Check Oil b. Check Tires c. Check Doors & Loaders d. Check Vehicle Lights e. Fill Fuel f. Get Route Assignment	These items are "standard" procedures, with experience to draw upon from the past. Vehicle should be designed such that maintenance checks can be made easily. These items are not time-critical. These items might be performed by maintenance personnel, not bus crew. Existing systems can provide data.
2. Transport Bus to First Bus Stop	
a. Monitor Engine b. Monitor Traffic c. Drive Bus	"Standard" driving procedures are employed. There is experience from the past to draw upon. Will bus make it similar to older (existing) busses in "drivability"? If so, nothing is really new here. Existing systems can provide data.

TABLE 21. Comments on Functions and Tasks. (Continued)

Functions and Tasks	Comments
3. Load Passengers	
a. Park at Bus Stop b. Open Door(s) c. Operate Loader(s) d. Load Bicycles e. Load Other Passengers f. Sell Tickets/Collect Fares g. Close Door(s) h. Secure Loader(s) i. Check Passengers' Positions	These items are a function of bus design (configuration) and bus crew size (one or two). Loader characteristics must be established. Who loads bicycles (bus crew, or riders)? How is fare collected? Operating times of doors and loader(s) must be obtained or estimated. All functions here are described by capacity and time required.
4. Transport Passengers to Next Bus Stop	
a. Monitor Engine Instruments b. Monitor Traffic c. Drive Bus d. Monitor Passengers e. Answer Passengers' Questions f. Communicate with Dispatcher	Part of this is the same as #2, above. We must establish the requirement for, and type of communication with dispatcher. Larger, transportation system operation study should be conducted. If not, assumptions as to communication must be made. Can passengers' questions be answered with the aid of some subsystem? Can such aids be suggested/recommended?
5. Unload Passengers	
a. Park at Bus Stop b. Open Doors c. Unload Passengers d. Operate Loader(s) (to Unload) e. Unload Bicycles	Same as #3 above. These items may be performed concurrently with #6 below. Bus layout and design configuration should address this possibility.
6. Load Passengers	
a. Operate Loader(s) b. Load Bicycles c. Load Passengers d. Sell Tickets/Collect Fares e. Close Doors f. Secure Loader(s) g. Check Passengers' Positions	Same as #3 above. These items may be performed concurrently with #5 above. Bus layout and design configuration should address this possibility.

TABLE 22. Modeling Checklist.

Functions and Tasks	A Effect on MOEs (Table 18)	B Affected by Conditions (Table 17)	C Items to be Modeled
1. Preparation			
a. Check Oil	Low	No	No
b. Check Tires	Low	No	No
c. Check Doors & Loaders	Low	No	No
d. Check Vehicle Lights	Low	No	No
e. Fill Fuel	Low	No	No
f. Get Route Assignment	Low	No	No
2. Transport Bus to First Bus Stop			
a. Monitor Engine Instruments	Low	No	No
b. Monitor Traffic	Low	No	No
c. Drive Bus	Low	Yes	Yes
3. Load Passengers			
a. Park at Bus Stop	Low	No	Yes
b. Open Door(s)	Low	No	Yes
c. Operate Loader(s)	High	Yes	Yes
d. Load Bicycles	High	Yes	Yes
e. Load Other Passengers	High	Yes	Yes
f. Sell Tickets/Collect Fares	Medium	No	Yes
g. Close Door(s)	Low	No	No
h. Secure Loader(s)	Low	No	No
i. Check Passengers' Positions	Low	No	No
4. Transport Passengers Next Bus Stop			
a. Monitor Engine Instruments	Low	No	No
b. Monitor Traffic	Low	Yes	No
c. Drive Bus	High	Yes	Yes
d. Monitor Passengers	Low	No	No
e. Answer Passengers' Questions	Low	No	No
f. Communicate with Dispatcher	Low	No	No

TABLE 22. Modeling Checklist. (Continued)

	A	B	C
Functions and Tasks	Effect on MOEs (Table 18)	Affected by Conditions (Table 17)	Items to be Modeled
5. Unload Passengers			
a. Park at Bus Stop	Low	No	Yes
b. Open Doors	Low	No	Yes
c. Unload Passengers	High	Yes	Yes
d. Operate Loader(s) (to Unload)	High	Yes	Yes
e. Unload Bicycles	High	Yes	Yes
6. Load Passengers			
a. Operate Loader(s)	High	Yes	Yes
b. Load Bicycles	High	Yes	Yes
c. Load Passengers	High	Yes	Yes
d. Sell Tickets/Collect Fares	Medium	No	Yes
e. Close Doors	Low	No	Yes
f. Secure Loader(s)	Low	No	Yes
g. Check Passengers' Positions	Low	No	Yes

TABLE 23. Expansion of Item 5 in Table 22.

Tasks	Conditions Affecting Tasks	Nature of Effect	Remarks
5. Unload Passengers			
a. Park at Bus Stop	Traffic Density	Minimal effect; high density may slow parking somewhat	Data from existing systems should apply
b. Open Doors	None	None	None
c. Unload Passengers	Wet street Rain Snow Snowy/icy streets	Each passenger disembarks slower than under good conditions	Data from existing systems should apply
d. Operate Loader	Hilly Rain Wet street Snowy/icy streets	Slows operation of loader. Each passenger disembarks slower	Data needed from simulator or submodel
e. Unload Bicycles	Snow Rain Snowy/icy streets	Slows each unloading operation	Bicycles may be unloaded simultaneously or serially by riders. Data needed from existing system or simulation.

A MOE component is often a measure of performance of an equipment component and/or its human operator. To illustrate the concept, we can create a couple of acronyms and write a couple of equations.

$$\text{MOEC} \equiv \text{MOP},$$

where MOEC is the MOE component and MOP is the measure of performance of the equipment or operator. Also, it may be that

$$\text{MOE} = \sum \text{MOEC} = \sum \text{MOP}.$$

The way the MOEC are combined (or summed) will vary with the nature of the MOE and MOEC. The reader should remember that simple addition of MOE components may not be representative of the actual situation. Hence, breaking down MOE into components is often a complex and challenging task, and deserves special attention.

The task of quantifying an MOE includes breaking it into its components, relating each to the system and mission, and showing how the components can be put back together again, analytically speaking. The steps to be taken in this process are shown in Table 24. Item #2 in Table 24 is illustrated with an example from the bus design case in Table 25.

TABLE 24. Steps in MOE Quantification.

1. Start with the MOEs listed and agreed upon earlier (Table 18 in our example).

2. Break each MOE into components, if possible, such that each can be related to the functions and tasks listed earlier. Include only those items to be modeled (Column C, Table 22 in our example).

3. If the MOE cannot be simply broken into components as in (2), develop the special definitions required to translate the system (or subsystem) performance into the appropriate MOE. These definitions can usually take the form of mathematical statements. Document the assumptions made in this process.

4. Indicate which equipment component(s) and/or human operator(s) are related to each MOE component. (The MOE component is really a measure of performance).

5. Indicate (qualitatively) how design decisions might be affected by the MOEs. For example, the passenger-loader with the shortest operating time would be preferred with everything else equal. (This item is an "extra" that reminds us why we are doing the analysis in the first place.)

6. Verify that the MOE components are compatible with any lower-level MOE that may be used in analysis or testing.

7. Show how the MOE components, or special MOE definitions, can be "reassembled" to form the top-level MOE first described (Table 18). A block diagram may be useful in this process.

8. Have MOEs that are formulated in item (3) above reviewed by any other analysts on the program and principal design team members (#1 and 6, Table 10).

TABLE 25. Example of MOE Steps for Item 5, Table 22.

Function	MOE
5. Unload Passengers	Total time from bus being within 30 feet of bus stop to when everything and everyone who wishes to has left the bus (T_1 in seconds).
Tasks	**MOEC**
a. Park at Bus Stop	Time required from being within 30 feet of Bus stop to coming to full stop (t_1 in seconds).
b. Open Doors	Time from coming to full stop to when doors are fully open so that passengers can get out (t_2 in seconds).
c. Unload Passengers (except handicapped passenger loader)	Time from when doors are fully open until last passenger has left and cleared the bus (t_3 in seconds). This is a function of the number of disembarking passengers and number of doors.
d. Operate Loader	Time from when bus comes to full stop to when all loader-passengers have been unloaded (t_4 in seconds).
e. Unload Bicycles	Time from when bus comes to full stop to when all bicycles have been unloaded (t_5 in seconds). This is a function of bicycle carrier characteristics, number of bicycles, and how they are unloaded.

NOTE: $t_1 + t_2 + t_3$ = time to unload walking passengers

t_4 = time to unload handicapped passengers; could be in parallel with $t_1 + t_2 + t_3$.

t_5 = time to unload all bicycles; could be in parallel with $t_1 + t_2 + t_3$.

T_1 = some combination (or largest of) the above.

Item #3 in Table 24 can be a very complicated and challenging process; it is not always straightforward. To illustrate, the MOEC shown in Table 25 are all times that can be easily combined to form the MOE for item #5. That MOE, in turn, can be combined with other times to get an estimate of the total time required for the same number of functions and tasks. But what is "timeliness" in Table 18? Can the MOE be modified to avoid defining routes, schedules, and numbers of busses assigned?

Modification of MOEs

At this point in the analysis it may be advisable to modify the MOEs to incorporate or reflect new information. Table 26 gives some comments on the pros and cons of MOE modification. Any modifications must be approved by the same people who reviewed the original MOEs.

TABLE 26. Advantages and Disadvantages in Modifying MOEs.

Advantages

1. Modification may be required as indicated by a more detailed look at the system and its operation. The original MOEs may simply not fit the situation.

2. Modification may better match the MOE components to the equipment and operator performance.

3. Modification may save some work (e.g. specifically describing a mission or scenario).

Disadvantages

1. Modification may not be acceptable to the sponsor (customer). It simply cannot be done if that is the case.

2. Modification will require another iteration in all work done to this point to insure compatibility.

Requirement

1. The modified MOEs must still serve the desired purposes (e.g. provide information for use in making design decisions).

2. If the modification to the MOEs is a simplification, the new MOEs should be useful in constructing the original MOEs if more time (resources) become available for analysis.

As an example, a modification of the MOE given in item 1, Table 18 could be:

> The total time required to complete one "cycle" in the bus mission, i.e. items 4, 5, and 6 in Table 22.

This MOE could be used to compare component design requirements, configurations, and operator performance under various operating conditions. Routes, schedules, and number of busses assigned to a given route need not be determined. The MOE could be accumulated to reflect a higher-level MOE: time to cover an entire route.

Another example of a MOE modification that might be pointed out is to severely downgrade item #2 in Table 18. The number of people that can be carried on the bus could be used as a simple MOE of the bus configuration. What mixes of sitting, standing, wheelchairs, etc. are feasible? This MOE will interact with the time MOE; it would probably be good to be able to conduct the design to maximize the number of people and minimize handling time, with comfort and safety requirements not violated. The number-of-people MOE could then be used in a higher level MOE (percent) when the demand for transporatation has been established (see Requirement #2 in Table 26). Downgrading to number of people avoids the work of having to establish the customer demand just now in the analysis.

Fifth Review

MOEs have been modified as appropriate, and expanded in some detail as per Table 25. A review and approval by managers, design team members, and sponsors (#5, 6, 7 in Table 10) is recommended before the effectiveness algorithm is built.

BUILDING THE ALGORITHM

An algorithm is a procedure for combining quantities, inputs, or data to get the desired result. The general concept is shown in Figure 8. Equations or data (or both) must be combined in a way that reflects the operating procedures, and that produces the desired results: the MOE.

All of the building blocks have been assembled. The tables that have been made up thus far show the tasks to be modeled, the measures of performance to be modeled, and the conditions affecting performance.

Graphic representations of the system and the functions to be performed may aid some in formulating the mathematics. A block diagram showing the sequence of operations may help (Figure 9). A geometric representation of system operation may be necessary to formulate the mathematics. An aircraft entering a traffic pattern for a landing would be such an example (Figure 10).

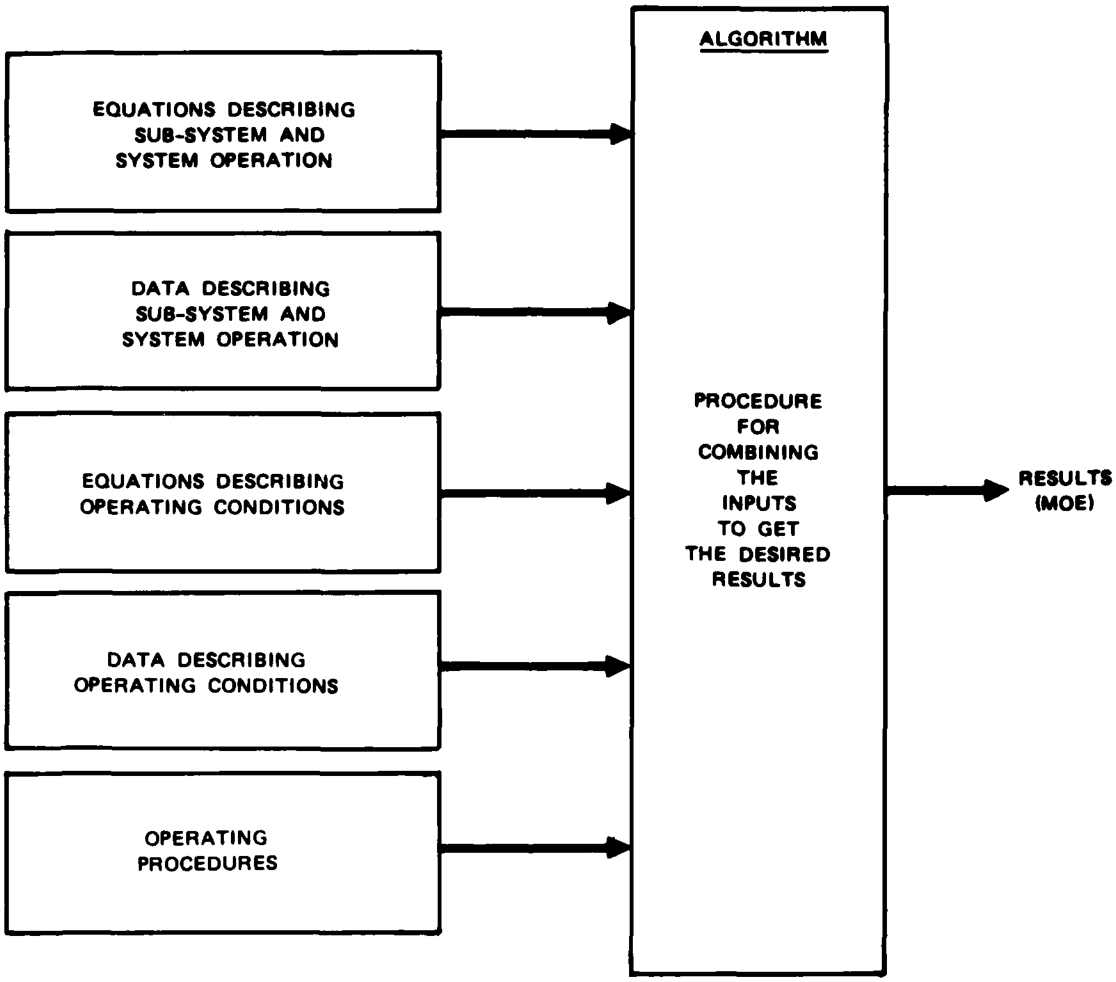
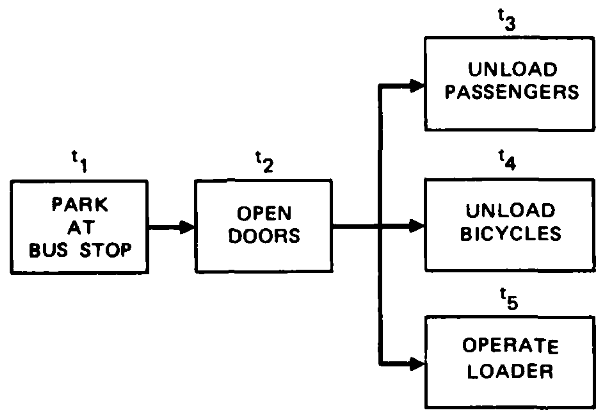


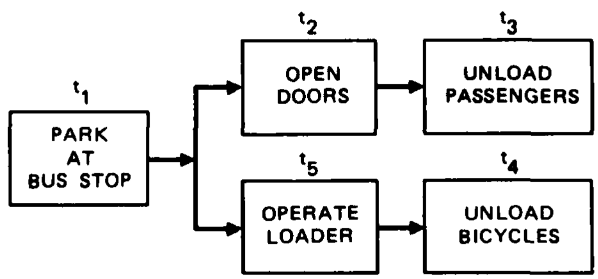
FIGURE 8. Concept of an Algorithm.

A.



$T_1 = t_1 + t_2 +$ LARGEST OF (t_3, t_4, t_5)

B.



$T_1 = t_1 +$ LARGEST OF $(t_2 + t_3$ OR $t_4 + t_5)$

FIGURE 9. Examples of Block Diagrams.

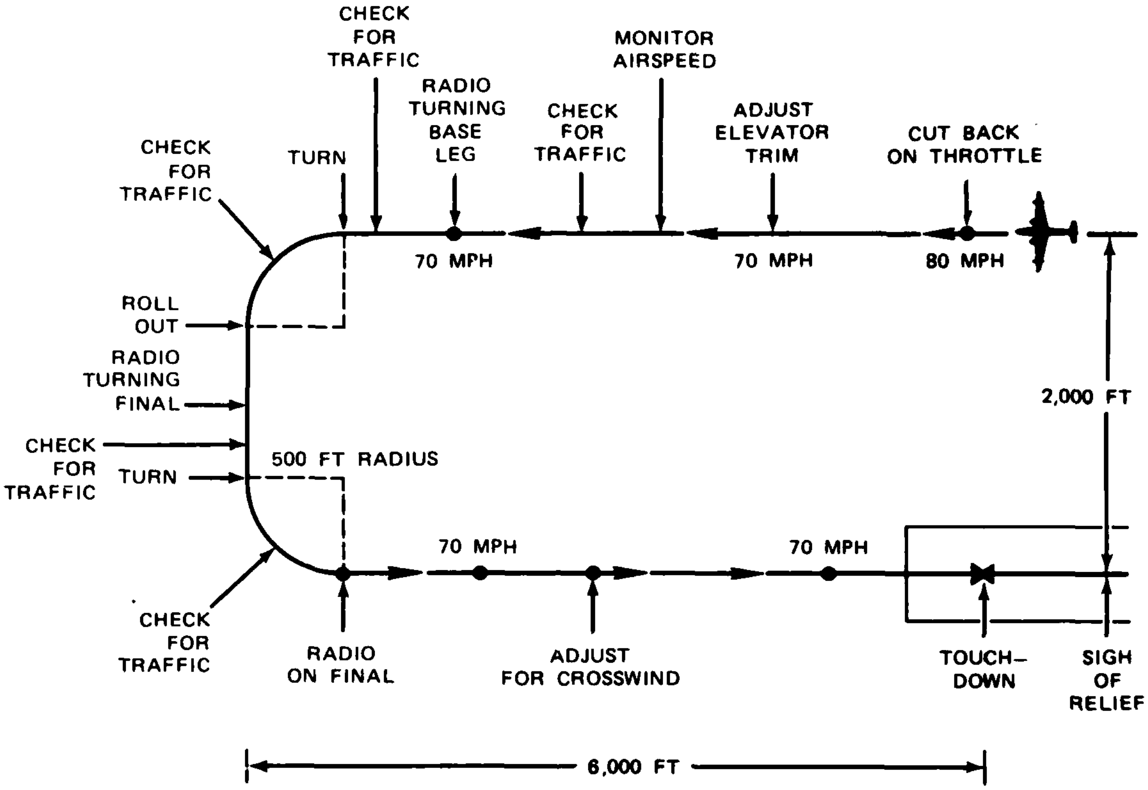


FIGURE 10. Example of Geometry Diagram with Distances, Velocities, and Initiation of Tasks Indicated.

Time points could be calculated from the distances and velocity; the time available for the various tasks can then be derived.

Figure 11 shows another geometric representation, where distance is a major parameter. Within limits, time is not a factor at all. The measure of effectiveness is the total number of shots required to get the ball from the tee into the hole on the green. The direction and endpoint of a longer shot (D_1, D_2, or D_3) should be planned as a function of terrain and wind. The distance itself is a function of skill and wind.

A top-level diagram can be used to show how the MOEs can be calculated (Figure 12). Each part of this top-level diagram can be expanded to show its components (Figures 9 and 13). Figure 13 also shows which conditions affect performance, and how performance can be calculated. At this point, the system components and operating conditions will have to be included in the formulation of the equations.

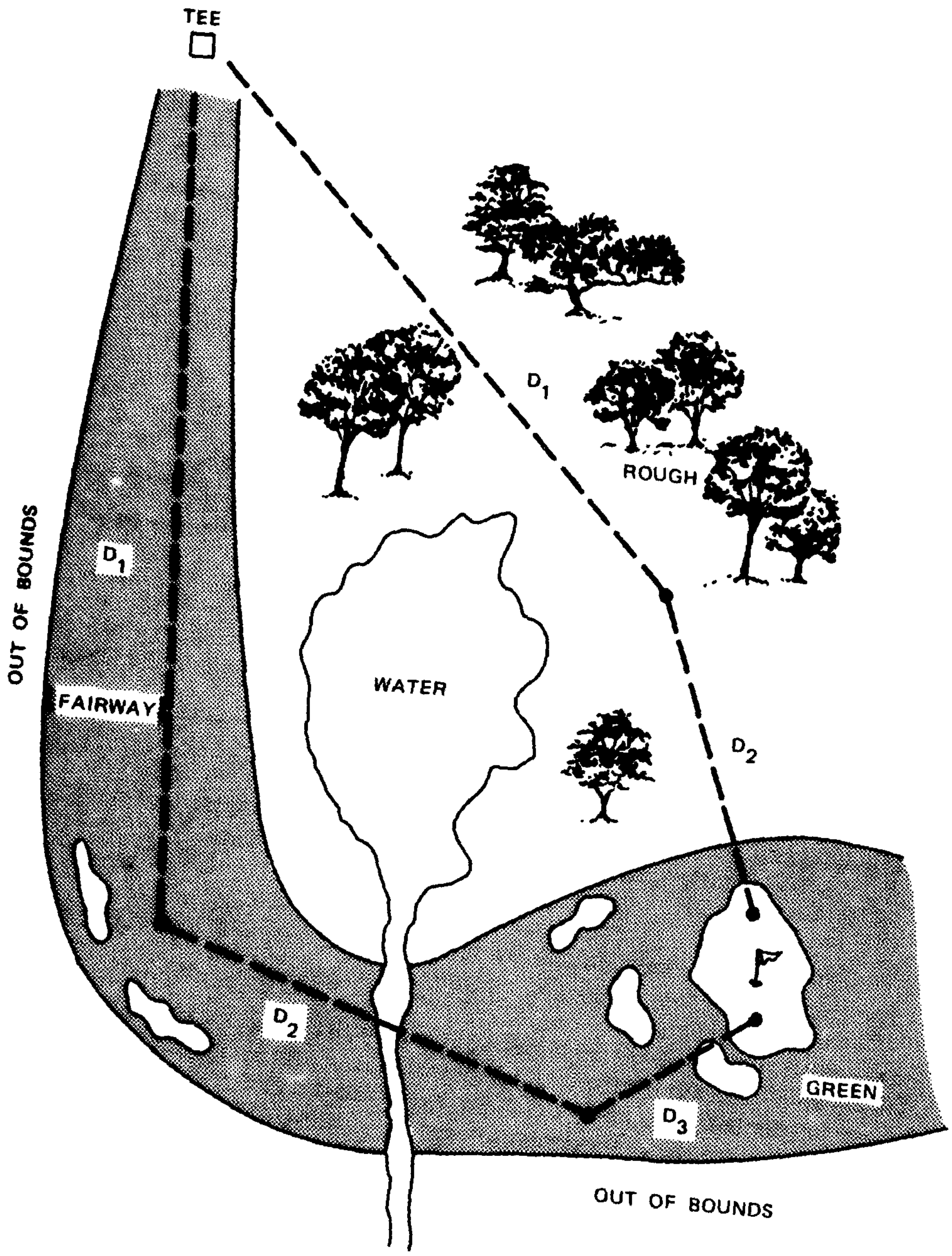
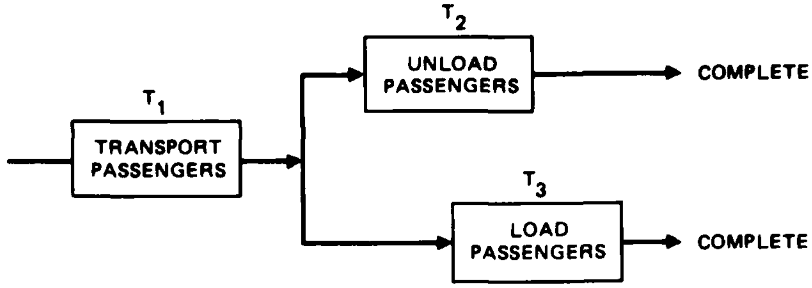


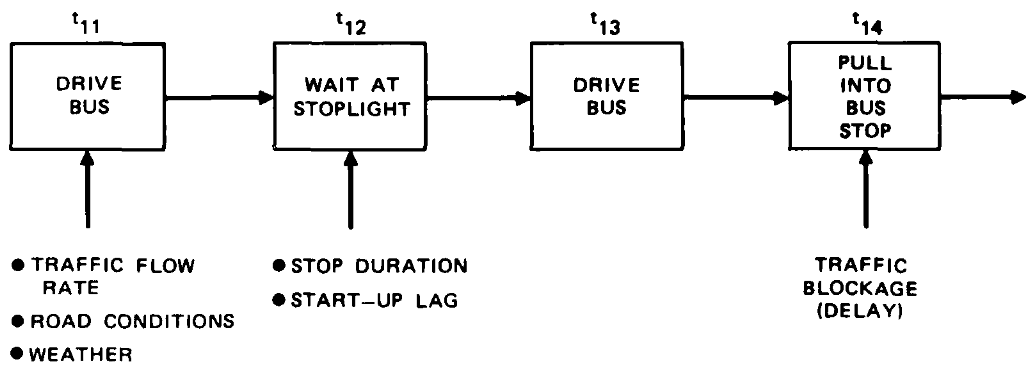
FIGURE 11. Example of Geometry Diagram with Distances and Number of Shots Indicated.



MOE = T_1 + OVERLAPPED COMBINATION OF T_2 AND T_3

T_1 = TIME TO DRIVE BUS BETWEEN STOPS.

FIGURE 12. Top-Level MOE Diagram.



$T_1 = n\ t_{11} + (n-1)\ t_{12} + t_{14}$

n = NUMBER OF STOPLIGHTS BETWEEN BUS STOPS

FIGURE 13. Expansion of T_1 in Figure 11.

The methods of describing component and/or operator performance already have been discussed in detail (see Figures 3, 4, 5, and 6). The analyst must use mathematical formulations, or actual descriptive data, whichever is most appropriate (and hopefully readily available) to estimate the performance of the lowest-level block in the algorithm (e.g., t_{12} in Figure 13). The method of combining the data associated with the MOE components must also be developed.

Selection of Models

The algorithm can be made up of both mathematical models (or computer simulations) and empirical data (e.g., traffic flow equations and weather statistics). The types of mathematical formulations to use depend upon the processes (operating proceures) being described, and the desired output.

A very useful text by Martin[30] gives definitions of different kinds of models; an expansion of these definitions is given below.

1. A deterministic model is an analytical representation of a concept, system, or operation in which there are unique outcomes for a given set of inputs. As an example, one total time to complete a bus "cycle" would be calculated from a set of inputs.

2. An expected value model is one in which the expected values (or means) are assigned to the chance parameters. Although in common use, this type of model can lead to great misunderstanding by the sponsor or customer.

3. A stochastic model is one in which the functional relationships depend on chance parameters (e.g., the weather conditions over a period of time). The outcomes for a given set of inputs can be predicted only in a probabilistic context. The probability of completing one cycle in less than various times would be a result (P = 0.95 in less than 1 hour, P = 0.80 in less than 50 minutes, etc.). Monte Carlo modeling is often used to make these calculations; that is, many, many calculations are made from random draws made from assumed variable distributions. These resultant calculations are then aggregated in some way to produce the final result.

A fourth model type that has limited use will be added to Martin's list.

4. A deterministic/probabilistic model is one which produces a unique outcome (a probability distribution) from distributions of input variables. Only one calculation is required as opposed to the thousands required in Monte Carlo modeling.

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[30] Martin, Francis F., Computer Modeling and Simulation, John Wiley & Sons, New York, 1968.

An algorithm can use all or some of the features of the four models listed above. The stochastic or deterministic/probabilistic models are often the most representative of the variability in the real world, but getting valid input data can be difficult.

The expected value model can be misleading when a number of "average" performances are combined. This point is important enough to justify a digression.

Digression: Using All the Data

Suppose three simple procedures as shown in Figure 12 comprise a unit, where

$$\text{MOE} = T_1 + T_2 + T_3$$

Figure 14 shows two possible distribution sets for each of the function times (data characteristics were shown in Figures 5 and 6). In Set A, each of the functions could take 5, 10, 15, or 20 seconds to perform, with equal probability. If one were to average a number of samples from the performance time distributions, the result would approach 12.5 seconds. Realistically, three different functions would have differently distributed times, however, as shown in set B, with different means as shown.

It is assumed in this example that the three times are independant of one another. Since this is not always the case, the analyst must examine the operating procedures closely to establish data independence. If there are appreciable intercorrelations in the data, these must be accounted for in the mathematical modeling.

The "average" MOE ($T_1 + T_2 + T_3$) for Set A is 37.5 seconds, and 41.5 seconds for Set B (the means are used to make the calculations).

Figure 15 shows the entire distribution of all possible MOEs for both sets A and B; the MOEs computed from the means would be exceeded about 42% of the time (1 - 0.58). If the MOEs are used somehow as design requirement numbers, 50 to 52 seconds would probably be better choices. People would prefer a system that does the job 95% of the time to one that works only 58% of the time.

Figure 15 illustrates the most complete form of an MOE, the probability distribution. All of the data (Figure 14) are used to form Figure 15. The distributions in the data are also implicitly included in Figure 15. Although the distributions shown in Figure 14 (A versus B) look quite different, the two MOE at the 95% level are 50 versus 52 seconds. The operational difference is probably negligible.

The analysis process does not make decisions, but it should provide the decision-maker with the information he needs. Stochastic models provide much more complete information than do expected value models. The cumulative curve, as shown in Figure 15, allows the decision-maker to see the whole picture.

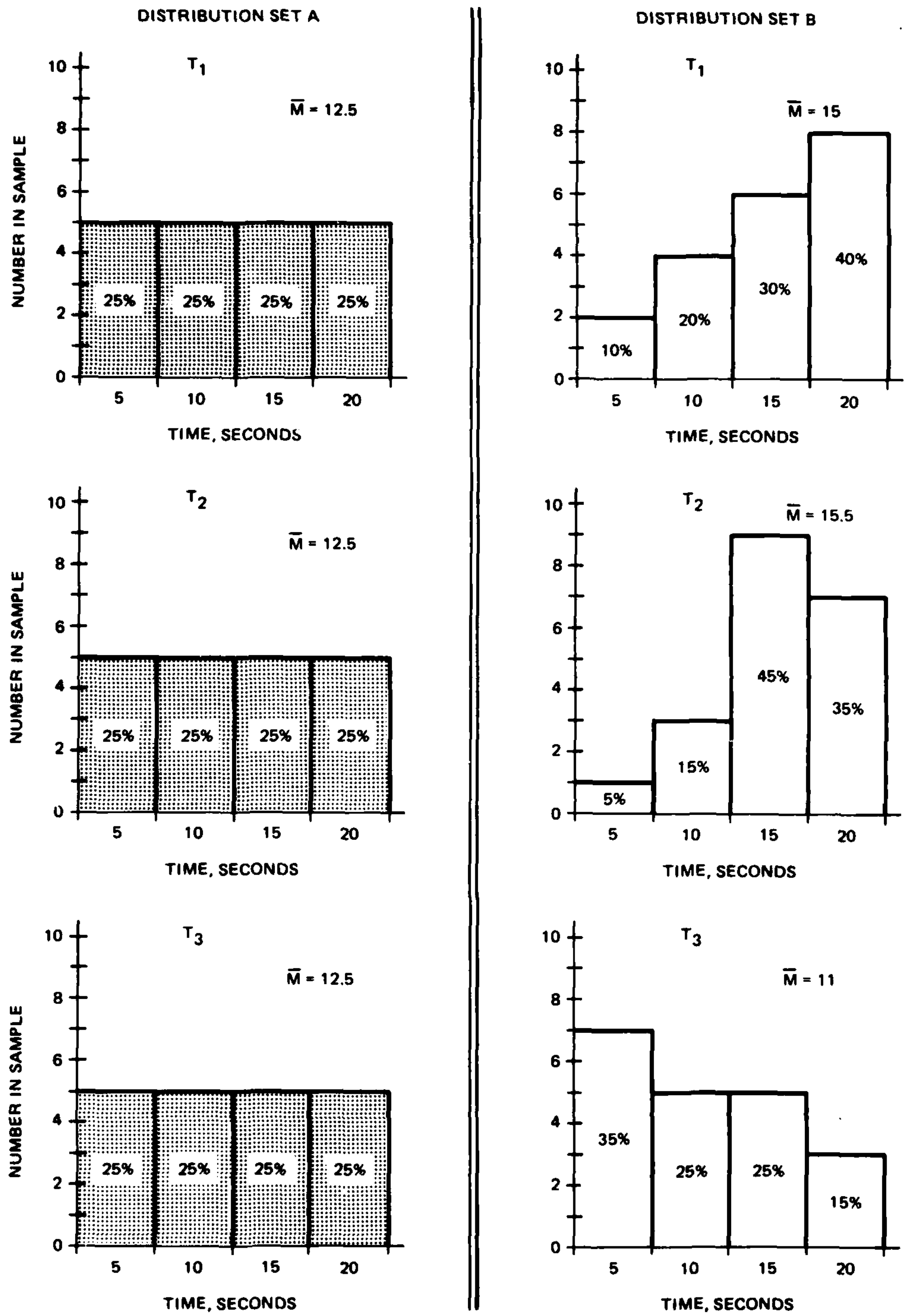

FIGURE 14. Two Distribution Sets of Times T_1, T_2, and T_3.

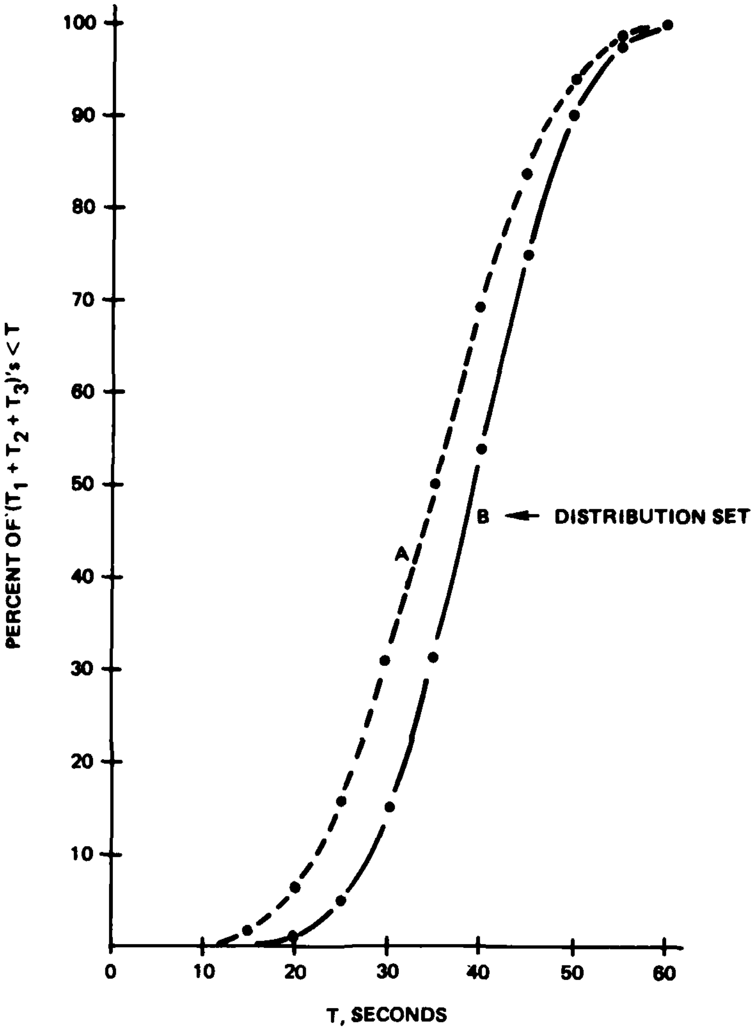

FIGURE 15. Cumulative Distribution of All Possible Combinations of $T_1 + T_2 + T_3$ as Shown in Figure 14. Components of the sum are weighted by the relative frequency of occurrence of each time.

Selection of Analytic Tools

Meanwhile, back at the ranch, the analyst is faced with selecting the methods, models, and mathematical tools to best describe his problem. Table 27 gives some characteristics of the models that have been discussed earlier. Table 28 gives a very superficial idea of the range of analytic techniques that can be used.

TABLE 27. Model Description.

1. Deterministic Model

   a. A single value of each input is used for any one complete calculation by the model.

   b. There are no variations in the model's output due to chance elements.

   c. All probabilistic elements are non-existent or removed from the problem.

   d. The output of a deterministic model is always the same for a given set of inputs.

   e. Deterministic model outputs can be used in parametric studies where the output can be plotted as a function of specific input values.

2. Expected Value Model

   a. Mean values are assigned to parameters which actually vary somewhat by chance; zero variance is assigned.

   b. No variance of the results is determined, and no distribution function of the results is determined.

   c. This model should be used when individual outcomes do not need to be known, when the model results are not affected by the variations of individual inputs, and/or when it is not necessary to determine the distribution function and variance of the model outcomes.

   d. The expected value criterion is useful in situations where the long-term average results are of primary interest.

3. Deterministic/Probabilistic Model

   a. Some of the inputs to the model are distributions of variables; the distributions can be either empirical (e.g. Figure 14) or analytical.

   b. One complete calculation by the model includes all the data in the input distributions.

   c. The output of the model can be probability distributions (Figure 15) which reflect the naturally occuring variability in the inputs. A model output is exact (i.e., not an approximation).

TABLE 27. Model Description. (Continued)

d. The deterministic/probabilistic model can be used when only a few input distributions are required, and the formulation are relatively simple. Otherwise, the computations get too complicated. It is used when data distributions (e.g. weather data, human performance) are required to accurately represent reality, and when probability distributions in the outcome are desired.

4. <u>Stochastic Model</u>

a. Some of the inputs to the model are distributions of variables (empirical or analytical).

b. One complete calculation by the model is made by choosing one value from each distribution for the inputs.

c. A very large number (thousands) of these calculations must be made for each set of conditions; usually a Monte Carlo simulation is used to accomplish this. The results are plotted as a distribution of outcomes. This distribution can be plotted cumulatively (see Figure 15) and described statistically (mean, standard deviation). The final result is an approximation that approaches the exact outcome as the number of calculations for each set of conditions increases.

d. Stochastic models are used when distributions in input data must be included, when a probability distribution for the output is appropriate, and when the model is too complicated to compute by the exact method. A high-speed computer is usually required.

TABLE 28. Some Analysis Techniques.

1. Statistical Description

   a. A statistical description of some sort is usually necessary to be able to describe the model inputs and outputs.

   b. Probability theory is used in these descriptions and in the formulation of many models and techniques.

   c. Discrete Probability Distributions and Continuous Probability Distributions are used in analytic and empirical studies.

2. Linear Programming

   a. Linear programming is used when the model contains unknown variables represented by algebraic symbols.

   b Restrictions or constraints in the model can be expressed as linear equations or inequalities which are linear functions of the unknown variables.

   c. The objective or MOE can also be expressed as a linear function of the unknown viariables.

   d. The MOE is to be maximized or minimized.

3. Queueing Theory

   a. Queueing Theory is applied to a situation where "customers" must wait in line to be "served." The customers can be people, parts to be repaired, or data to be stored or used in computations. The server can be a person, a computer terminal, a message buffer, or a machine.

   b. Queueing analysis considers the number of servers, the serving discipline (e.g. first-come-first-serve), number of customers in the queue, service rate, and customer arrival rate and pattern. Distributions of these parameters can be handled analytically.

   c. It is usually assumed that the random variable corresponding to the times between customer arrival in the queue are independent and identically distributed. It is also usually assumed that the service times are independent and identically distributed random variables.

   d. Common outputs desired from a queueing model are expected number of customers (or units) in the queue and in the whole system under steady state conditions, and expected time spent by a customer (or unit) in the queue and in the whole system under steady state conditions.

TABLE 28. Some Analysis Techniques. (Continued)

4. Control Theory

a. Control Theory is applied to any situation where it is desirable to control a process such that specified states are maintained. Controlling or maintaining the speed of an engine, turntable, or cassette tape drive, the altitude of an aircraft, or water flow to a generator all require some control.

b. Many analytical techniques have long been in use to describe control systems and estimate their stability and accuracy. Use of differential equations, Laplace transform, and the root-locus method have been used to model linear, dynamic systems.

c. The human operator has also been modeled in situations where he must observe a process, estimate its states, and generate a control action. This work has included the design of displays, controllers, and control mechanism characteristics used by the operator.

5. Game Theory

a. Game Theory is a collection of mathematical models applied to the behavior of "players" who try to modify the state of a system to attain specified goals. The situation being modeled is one oi cooperation, or one of competition or conflict. Conflict arises when two or more players have conflicting goals (such as shoot the other player down).

b. A model, or game is defined by its goals and its operating rules, or strategy. A strategy is a complete description of how a player will behave, or what decisions he will make under every possible circumstance.

c. Game Theory provides guidelines for rational behavior when confronted with tactical or strategic decisions. The game model describes all potential payoffs, and identifies actions required to get the best possible outcome in light of the options open to the opponents in the game. It uses optimization procedures, statistics, probability, and classical decision theory.

d. Game Theory is used to assess tactics (strategy), and to study decision-making, but has not been used much in determining design requirements. It is a useful tool, however, where system characteristics such as weapon standoff range could interact strongly with system employment.

Developing more specific recommendations for selection of analytic techniques is beyond the scope of this report, as well as beyond the author. As Martin[30] advises,

1) look at the real world.
2) study the problem.
3) examine the desired results of the model.
4) examine resources available and time schedule.
5) select the right procedure at the right place in the model.
6) document the rationale for the selections made.

We must not forget the consultants on our analysis team (#3, Table 10). They can certainly advise when presented with the information assembled thus far, and may even have to be enlisted to do the work. References 19 and 31 to 40 will provide more detailed information for the really motivated.

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[31] Rouse, William B., Systems Engineering Models of Human-Machine Interaction, Elsevier North Holland, Inc., New York, 1980.

[32] Allen, Arnold O., Probability, Statistics, and Queueing Theory, Academic Press, New York, 1978.

[33] Phillips, D. T., et al, Operations Research, Principles and Practice, John Wiley & Sons, Inc., New York, 1976.

[34] Buffa, E. S. and J. S. Dyer, Management Science/Operations Research: Model Formulation and Solution Methods, John Wiley & Sons, Inc., New York, 1977.

[35] Emshoff, J. R. and R. L. Sisson, Design and Use of Computer Simulation Models, The MacMillan Co., New York, 1970.

[36] Boeing Aerospace Company, Analyst's Guide for the Analysis Sections of MIL-H-46855, by Charles W. Geer, Report D180-19476-1, 30 June 1976, Seattle, Washington.

[37] Davis, Morton D., Game Theory: A Nontechnical Introduction, Basic Books, Inc., New York, 1970.

[38] Blaquieve, A., et al, Quantitative and Qualitative Games, Academic Press, New York, 1969.

[39] Game Theory and Its Applications, American Mathematical Society, Providence, Rhode Island, 1981.

[40] Lucas, W. F., An Overview of the Mathematical Theory of Games, Management Science, Vol. 18, No. 5, January 1972, Part 2.

SUMMARY OF PROCEDURES

The steps in algorithm development that have been described above are summarized in two ways. For those with a high verbal aptitude, a simple list of the steps is given. For those of us who like pictures, Figures 16, 17, and 18 show the steps in block diagram form. The tables of instruction given throughout the text are also reproduced so that they will be available in one place.

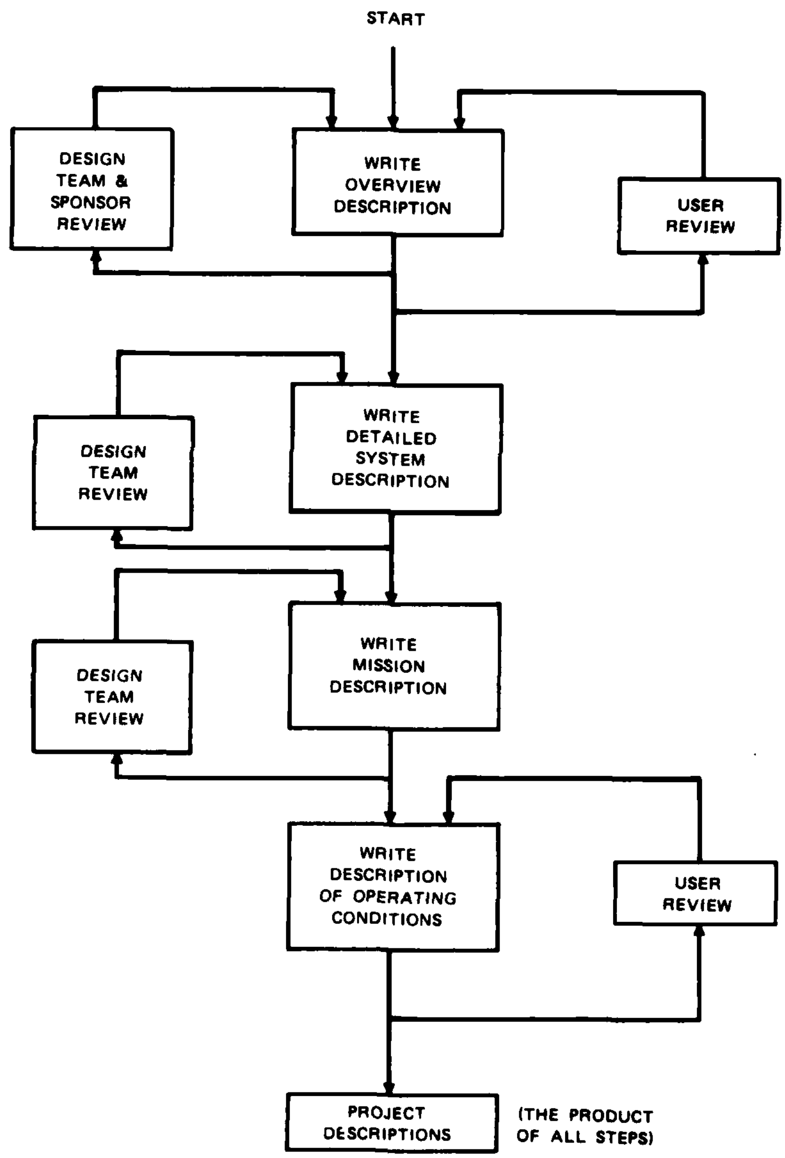

FIGURE 16. Steps in Describing What the System Is All About.

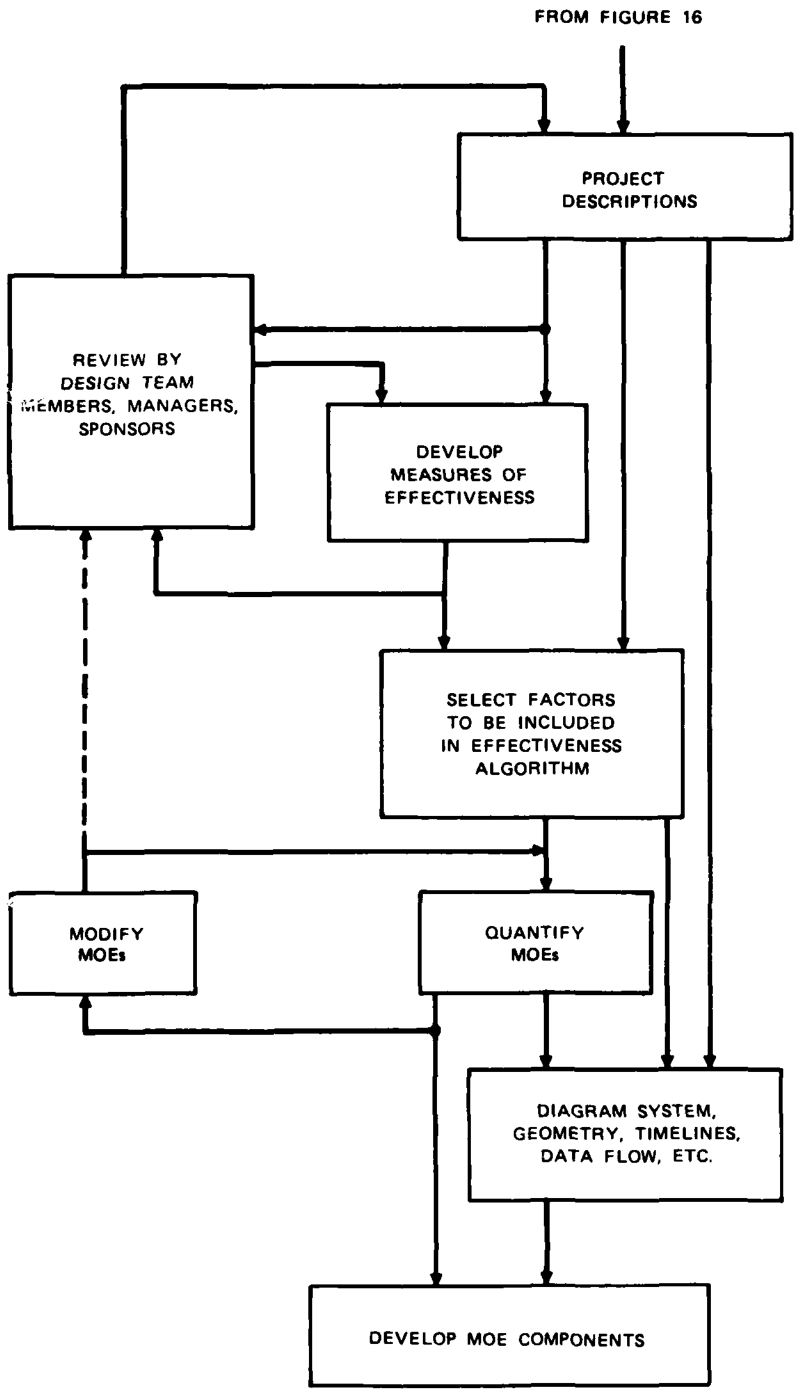

FIGURE 17. Initial Steps in Effectiveness Algorithm Development.

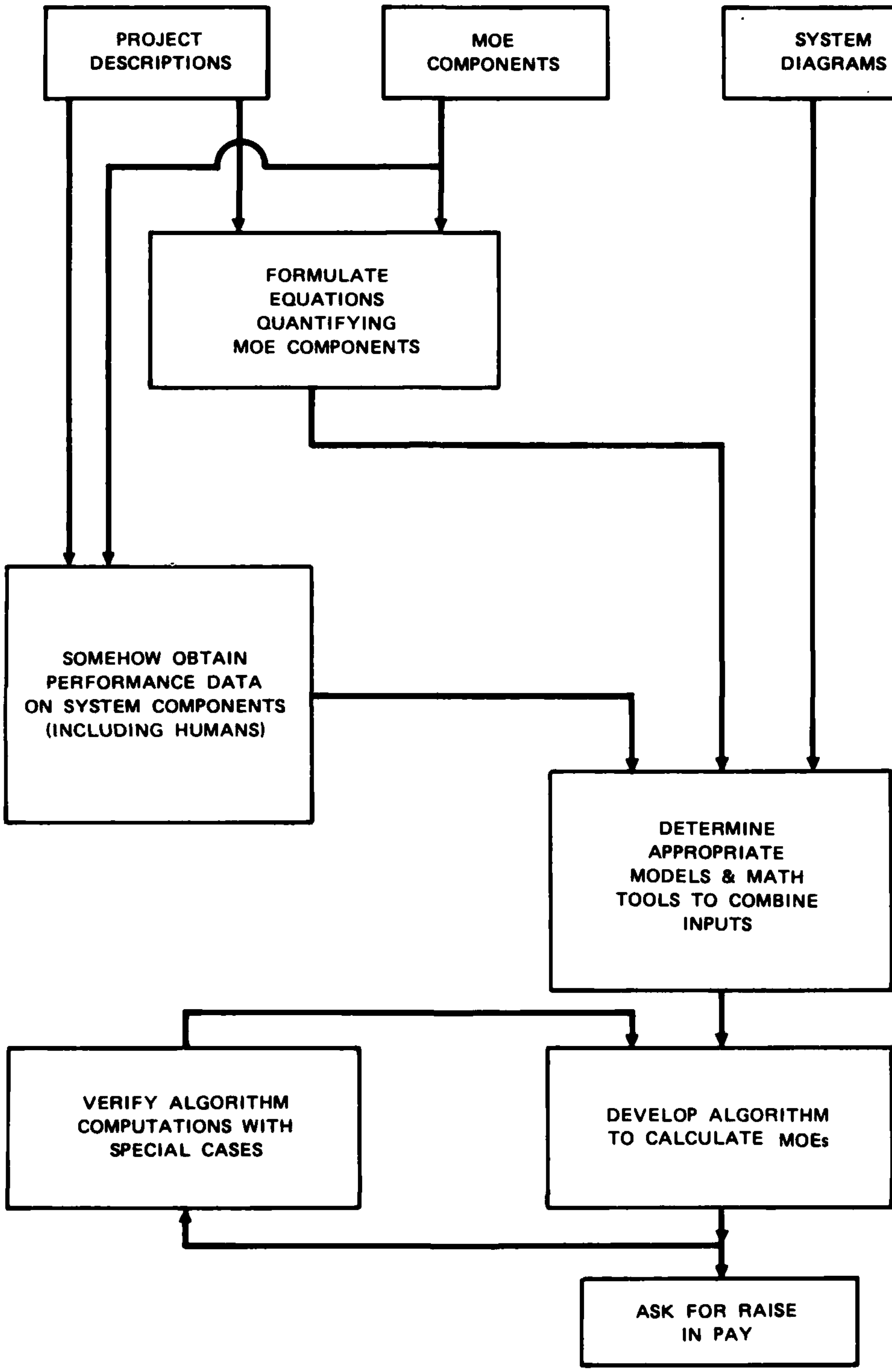

FIGURE 18. Final Steps in Effectiveness Algorithm Development.

PREPARATORY DOCUMENTATION

1. Write an overview description of the system and the way it will be used. (Table 29).

2. Have the overview description approved by other principal design team members and by the project sponsors.

3. Make changes in overview description as per review comments.

4. Have the overview description reviewed by users of a related or similar system.

5. Incorporate users' review comments into overview description.

6. Write a detailed system description including alternate configurations being considered and showing where design decisions must be made. (Table 30).

7. Have the detailed system description reviewed by the principal design team members.

8. Negotiate and incorporate changes in the detailed system description.

9. Write a mission description which indicates how the system will be used and what functions must be performed to insure mission success; alternate operating modes should be included. (Table 31).

10. Have the mission description reviewed by the design team members.

11. Incorporate changes in the mission description resulting from the review.

12. Write a description of the operating conditions, including the environments of both the hardware/software and the human operators.

13. Have the operating conditions reviewed by the user community.

14. Incorporate changes resulting from user review.

15. Develop Measures of Effectiveness to be used in system effectiveness studies (Table 32).

16. Have System Description, Missions, Operating Conditions, and MOEs reviewed by principal design team members, program managers, and sponsors. This is the whole picture; is it acceptable by everyone?

17. Incorporate changes resulting from the reviews in (16).

BUILDING THE ALGORITHM

18. Select functions and tasks, system components, and environmental factors that must be included in the system effectiveness algorithm. (Table 33).

19. Quantify the MOEs that were developed in (15). (Table 34).

20. Modify the MOEs as required (Table 35).

21. If MOE modification is major, have the new MOEs approved by same group as given in (16).

22. Draw block diagram(s) showing functions to be performed in sequence (in series and/or parallel as appropriate).

23. Draw diagrams showing applicable geometry and/or time lines as appropriate.

24. Relate diagrams in (22) and (23) to system components, MOEs, and operating conditions.

25. Break MOEs developed in (19) into components (if appropriate) that correspond to the diagrams built under (22) and (23).

26. Get estimates from experts or consultants of the availability and source of performance data (use something like Table 9) for each component, including the human operator(s).

27. Formulate equations or get data (e.g. in the form of look-up tables) that describe system component performance (including the human operator) in terms of the MOE components. The equations or data should characterize (a) the naturally occurring distributions in the data (Figure 14), and (b) the effects of environmental operating conditions (e. g. acceleration, weather).

28. Develop procedures for combining the MOE components to produce the desired MOEs. This step entails selecting mathematical tools and/or models (Tables 27 and 28) appropriate to the particular problem. Consultation with, or active participation by specialists (e.g., mathematicians) will probably be required. The resultant MOE should be either of the Stochastic or Deterministic/Probabilistic type (Table 27) such that any desired level of system effectiveness (Figure 15) can be determined.

29. Verify the algorithm's internal consistency with several special sets of inputs for which the outputs can be predicted. It is important to be able to explain the algorithm's outputs in terms directly related to the real world: system characteristics, operator performance, and operating conditions.

TABLES OF INSTRUCTIONS

TABLE 29. Steps to be Taken in Producing an Overview Description.

1. Define and Document the Objective.
2. Define and Document Special Requirements.
3. Define and Document the System (broken into Major System Components).
4. Define and Document the Operator(s) Characteristics.
5. Identify and Document the Operating Times, Places, and Environmental Conditions (see Table 3).
6. Identify and Document Other Factors or Entities Affecting System Operation, (See Table 3).
7. Describe and Document the Operating Concepts.
    a. How will the system be used?
    b. What role do major system components play?
8. Determine General System Measures of Effectiveness.

TABLE 30. Steps in System Description.

1. Use information describing the system that already exists.
2. Include only those components that are thought to relate to overall system effectiveness. Keep this first description general; don't describe the detailed parts of a component.
3. Identify design decisions yet to be made on specific components. That is, indicate which components are still selectable, and indicate the range in characteristics that is still possible.
4. Include alternative configurations if a specific one has not yet been adopted.
5. Have the system description reviewed by the design team.

TABLE 31. Notes on Mission Description.

1. List and briefly describe functions that must be performed to accomplish the mission.

2. List and briefly describe the major tasks required in each function. A function and task allocation is implied here. It should have been done elsewhere as part of the human factors work on the program. It may have been done implicitly by the design engineers.

3. Do the above (1 & 2) for each configuration and mission, or show branches in the appropriate mission segments to include the alternatives.

4. Construct mission profiles for illustrating the concepts to reviewers. Those for aircraft missions sometimes show the flight path plotted by altitude and ground-track with functions or tasks indicated. Others can show a timeline, with the function or tasks shown in the proper sequence.

5. Note assumptions, alternatives, questions, or issues that come up in doing this work. This side information may prove helpful later, or must be resolved if controversial. A systematic procedure should be established to keep a record of changes in the missions as the development of the system progresses.

6. Have completed missions reviewed by design team and users.

TABLE 32. Measures of Effectiveness (MOEs).

MOEs should:

1. Be required in some decision process (e.g., component selection).

2. Include aspects of the physical environment that affect operator and system performance.

3. Use variables that are readily measurable in the real world, and/or for which there is a data base.

Some Guidelines for Developing MOEs

1. List important mission features so that the MOEs have a better chance of reflecting the way a mission must be conducted in order to be effective.

2. Develop a list of conceivable MOEs for the missions; this brainstorming session should be conducted without constraints (list all possibilities).

3. Reduce the list by discarding duplication and MOEs that are not in some way related to the mission objectives.

4. Write brief discussion of each of the MOE and tabulate some of the general characteristics of each MOE.

5. Categorize the MOEs into groups of similar measures.

6. Select the best MOEs in each group using a procedure to evaluate those that are strong or weak, or alike or similar.

7. Point the selected MOEs to the next higher level of objectives: i.e., insure that the MOEs are so constructed that they can serve as performance indicators to the next higher level.

8. Express the MOEs in standard notation of physics, engineering, and mathematics (i.e.,time required, distance covered, percent defects identified).

TABLE 33. Steps in Selecting Items to be Modeled.

1. Augment the list of functions and tasks with comments, remarks, or observations to provide a more complete description of the items.

2. Estimate the strength of the effect on the MOEs of each of the tasks. Include secondary effects.

3. Indicate which tasks are affected by the operating conditions listed earlier. Pair up specific tasks with the specific operating conditions.

4. Make a preliminary decision as to what parts of the system and system operation should be modeled.

5. Document the above.

TABLE 34. Steps in MOE Quantification.

1. Start with the MOEs listed and agreed upon earlier.

2. Break the MOEs into components, if possible, such that each can be related to the functions and tasks listed earlier. Include only those items to be modeled.

3. If the MOEs cannot be simply broken into components as in (2), develop the special definitions required to translate the system (or subsystem) performance into the appropriate MOEs. These definitions can usually take the form of mathematical statements. Document the assumptions made in this process.

4. Indicate which equipment component(s) and/or human operator(s) are related to each MOE component. (The MOE component is really a measure of performance).

5. Indicate (qualitatively) how design decisions might be affected by the MOEs. (This item is an "extra" that reminds us why we are doing the anlaysis in the first place.)

6. Verify that the MOE components are compatible with any lower-level MOEs that may be used in analysis or testing.

7. Show how the MOE components, or special MOE definitions, can be "reassembled" to form the top-level MOE first described. A block diagram may be useful in this process.

8. Have MOEs that are formulated in item (3) above reviewed by any other analysts on the program and principal design team members.

TABLE 35. Advantages and Disadvantages in Modifying MOEs.

Advantages

1. Modification may be required as indicated by a more detailed look at the system and its operation. The original MOEs may simply not fit the situation.

2. Modification may better match the MOE components to the equipment and operator performance.

3. Modification may save some work (e.g.,specifically describing a mission or scenario).

Disadvantages

1. Modification may not be acceptable to the sponsor (customer). It simply cannot be done in this case.

2. Modification will require another iteration in all work done to this point to insure compatibility.

Requirement

1. The modified MOEs must still serve the desired purposes (e.g. provide information for use in making design decisions).

2. If the modifications to the MOEs are simplifications, the new MOEs should be useful in constructing the original MOEs if more time (resources) become available for analysis.

IMPLICATIONS FOR HUMAN FACTORS EXPERIMENTS

The problem of finding applicable human performance data for use in analysis has been discussed in the main text as well as in Appendix C. Some of the inadequacies in the data are given below.

1. Most experiments include only one or two variables, whereas the real world situation may have several variables which can affect performance.

2. Sometimes the experiments do not include the variables of interest at all, even though the general situation and performance measures may be applicable.

3. The range of the variables (e.g., 65 to 80°F) may not be the range estimated in the employment of the system.

4. The subjects in the experiment may not be taken from the population that would be using the system (e.g., female schoolteachers versus male fighter pilots).

5. The experiment may not have been conducted in the context of system operation.

6. All of the data (e. g., Figure 14) are not reported. Only means or analysis of variance tables, or the like, are given.

Simon[41,42] and Williges[43] provide considerable discussion on the shortcomings of human factors experiments and, more importantly, recommend experimental designs that will improve the results. The designs allow an experimenter to include a large number of variables in a series of experiments.

Experimenters could improve the applicability of their results by including conditions of no immediate interest. For example, a wider range of values for selected parameters could be used than called for in the anticipated application without compromising the primary objective of the experiment.

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[41] Simon, Charles W., New Research Paradigm For Applied Experimental Psychology: A System Approach, Canyon Research Group Report CWS-04-77, October 1977, Westlake Village, Calif. (USAF Contract No. F44620-76-C-0008.)

[42] Simon, Charles W., Design, Analysis, and Interpretation of Screening Studies for Human Factors Engineering Research, Canyon Research Group Report CWS-03-77, September 1977, Westlake Village, Calif. (USAF Contract F44620-76-C-0008.)

[43] Williges, Robert C., "Development and Use of Research Methodologies for Complex System/Simulation Experimentation," in Manned Systems Design, Methods, Equipment, and Applications, Plenum Press, New York, 1981.

It is common that subjects for experiments are selected ("drafted" is often more appropriate) from beginning psychology classes or from the experimenter's colleagues. A special effort should be made to (1) specify the most likely user population, and (2) select subjects from this population.

Conducting an experiment in the context of system operation can be one of the most unattainable corrections to the above deficiency list, primarily because of economics. The limited availability and/or high cost of operating an appropriate simulator may preclude its use. The experimenter must often settle for less. There is no solution to this problem, other than to be aware of the spectrum of data sources (Table 6), try to get the "best," and interpret the resulting data accordingly.

And for heaven's sakes, report all of the data! It won't cost that much more.

Appendix A

ADDITIONAL BACKGROUND MATERIAL

SYSTEMS

Several definitions of systems have been given in the human factors literature. Examples are given below.

> A system is "a number of parts which are connected together in order to transform a given set of inputs into a given set of outputs." (Jones, reference 16).

Jones also gives 11 categories for classifying systems according to mode of operation and physical nature of their components and couplings.

> "A man-machine system can be viewed as any organized group of activities, involving men and machines, directed towards the solution of a given problem or set of problems and operating within the constraints of a given environment." (Corkindale[44]).

> "A system is a set of interacting components. Components are physical entities such as human operators or electric motors or planets. Interaction implies that they are capable of exchanging energy and information. Assuming that the designer is behaving rationally, every man-made system must have a purpose: That is, a set of objectives." (Singleton[9])

> "A system is an organization in which the individual elements work together purposefully to produce an output which the individual element cannot produce by itself." (Meister[45])

> "A man-machine system is essentially a concept based on certain assumptions (to be described later); it is an abstraction, not a physical configuration or a type of organization." (Meister[13])

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[44] Corkindale, K. G., "Man-Machine Allocation in Military Systems," ERGONOMICS March 1967, Vol. 10, No. 2, pp. 161-166.

[45] Meister, David, "A Systematic Approach to Human Factors Measurement," Navy Personnel Research and Development Center, October 1978.

"Consequently, the concept of a "system" is an abstract, devised, synthetic entity. ... it is a "system" only because someone views it from a given point of reference. He sees an organization or an integration of forces or events for which he can define a set of boundaries." (Chase[10])

SYSTEMS DESIGN PROCEDURES

Procedures to be followed in systems design and development have been diagrammed by several authors. Figures A-1 through A-6 illustrate the various concepts and procedures; they illustrate that there is more than one way to skin a cat, as my grandfather used to say. Figure A-7 lists some of the parameters included in the analysis procedures.

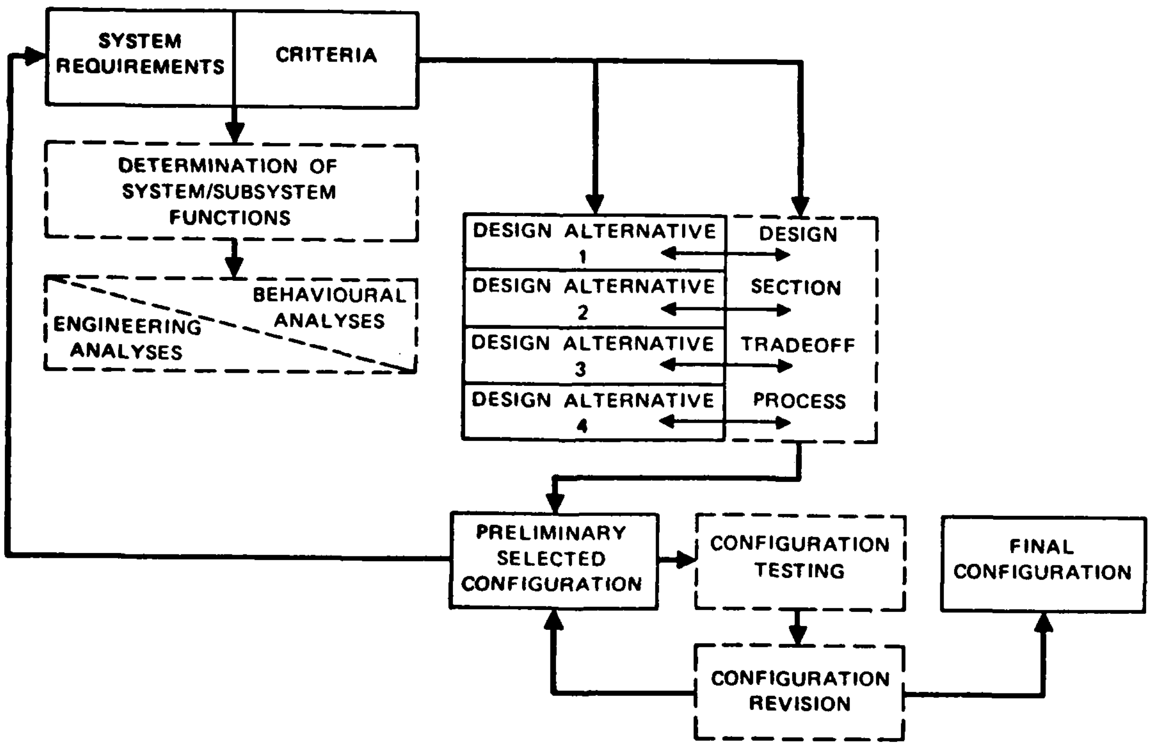

FIGURE A-1. The System Development Process (from Meister[15]).
(Note: Broken boxes represent analyses; unbroken boxes, inputs/outputs)

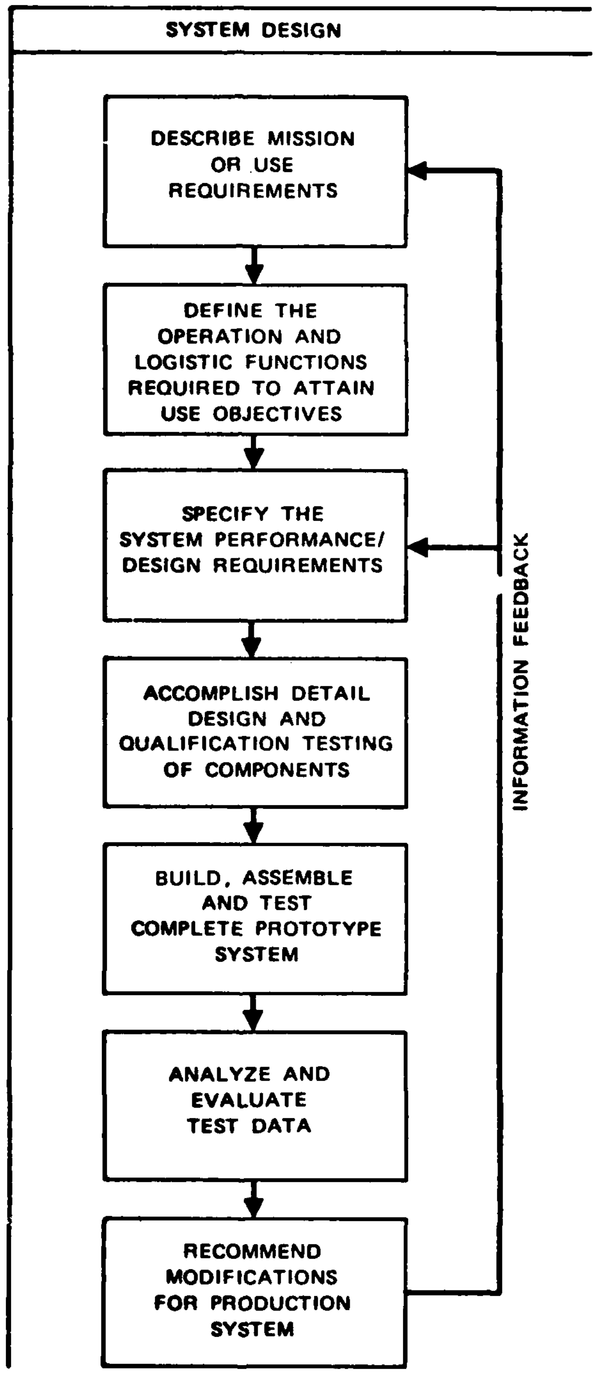

FIGURE A-2. General Steps in Systems Design (from Chase, reference 10).

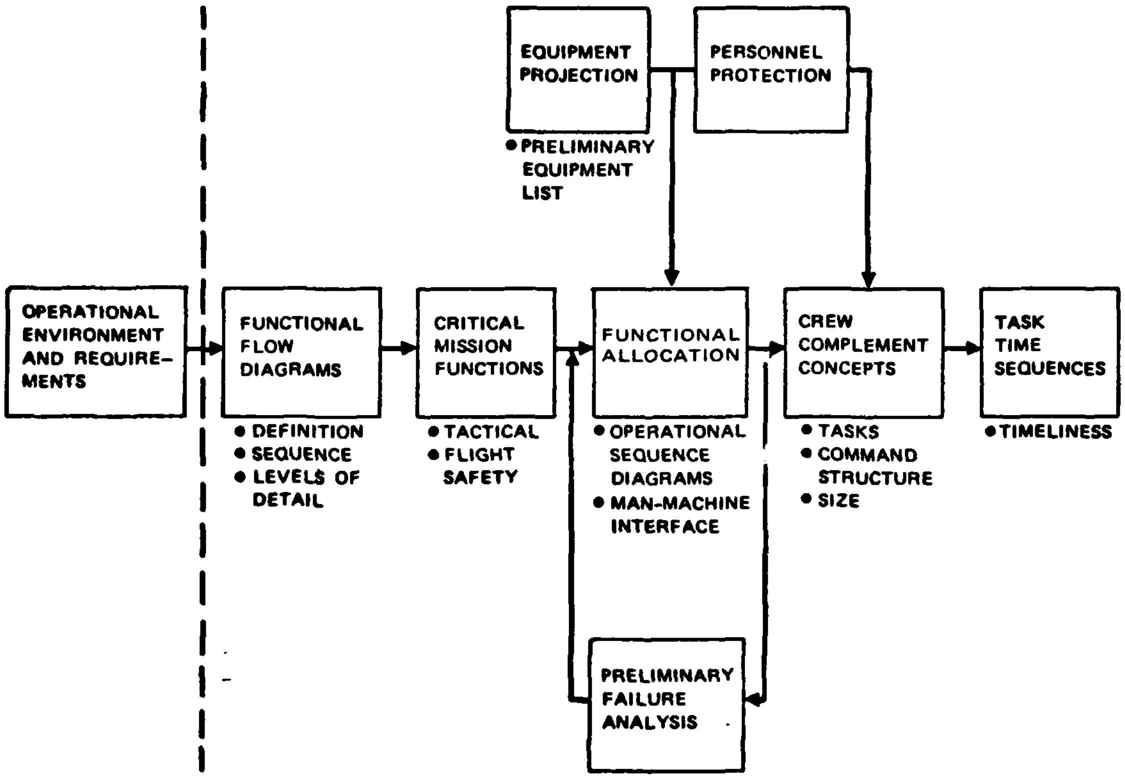

FIGURE A-3. Functional Analysis[32].

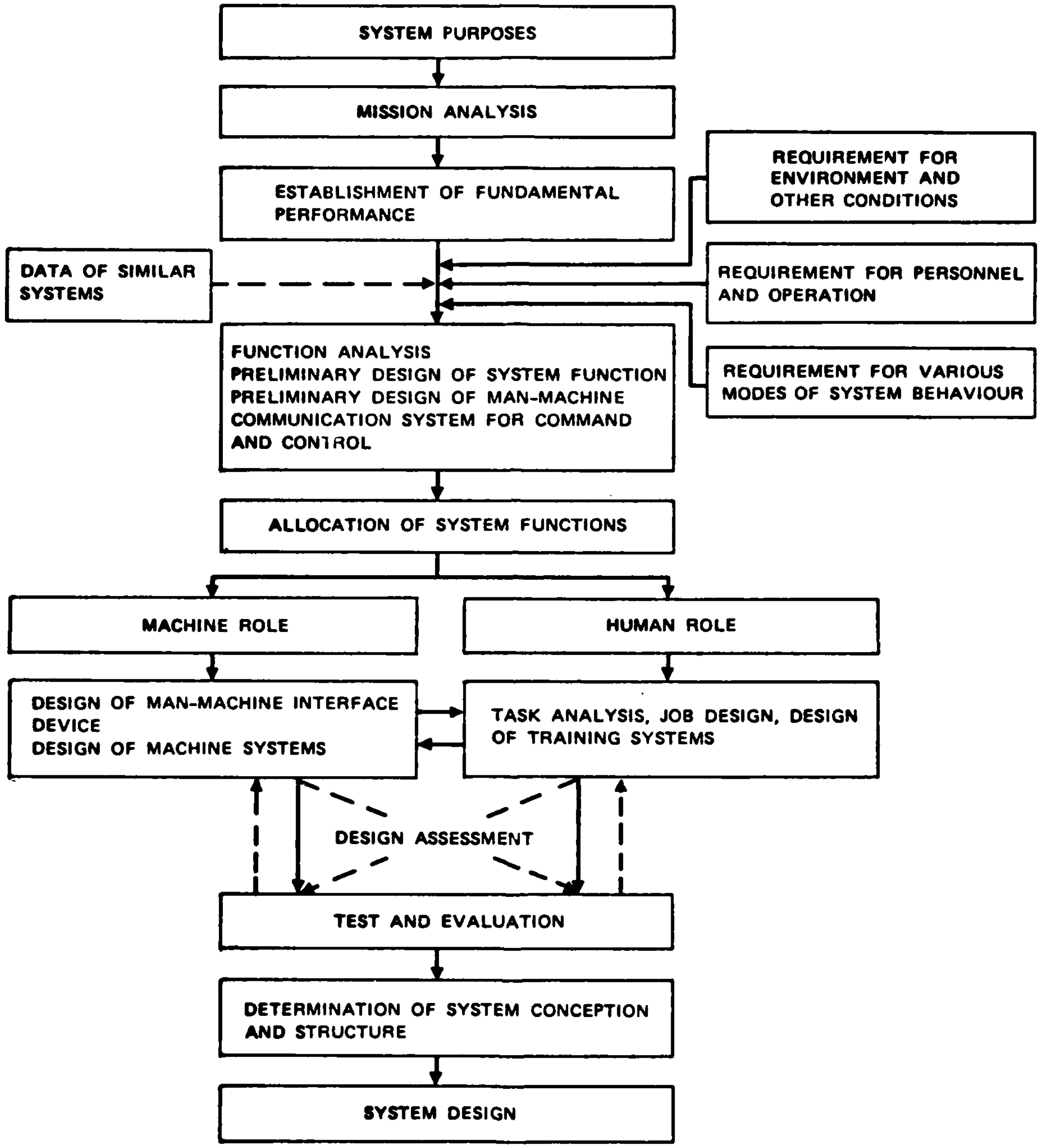

FIGURE A-4. Typical Procedure for Determining System Conception and Structure (Iiyama[46]).

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46 Iiyama, Yuji, "Systems-Ergonomic Approaches to Design and Operation of Today's Railroads," Human Factors 1980, Vol 22, No. 1, pp. 15-24.

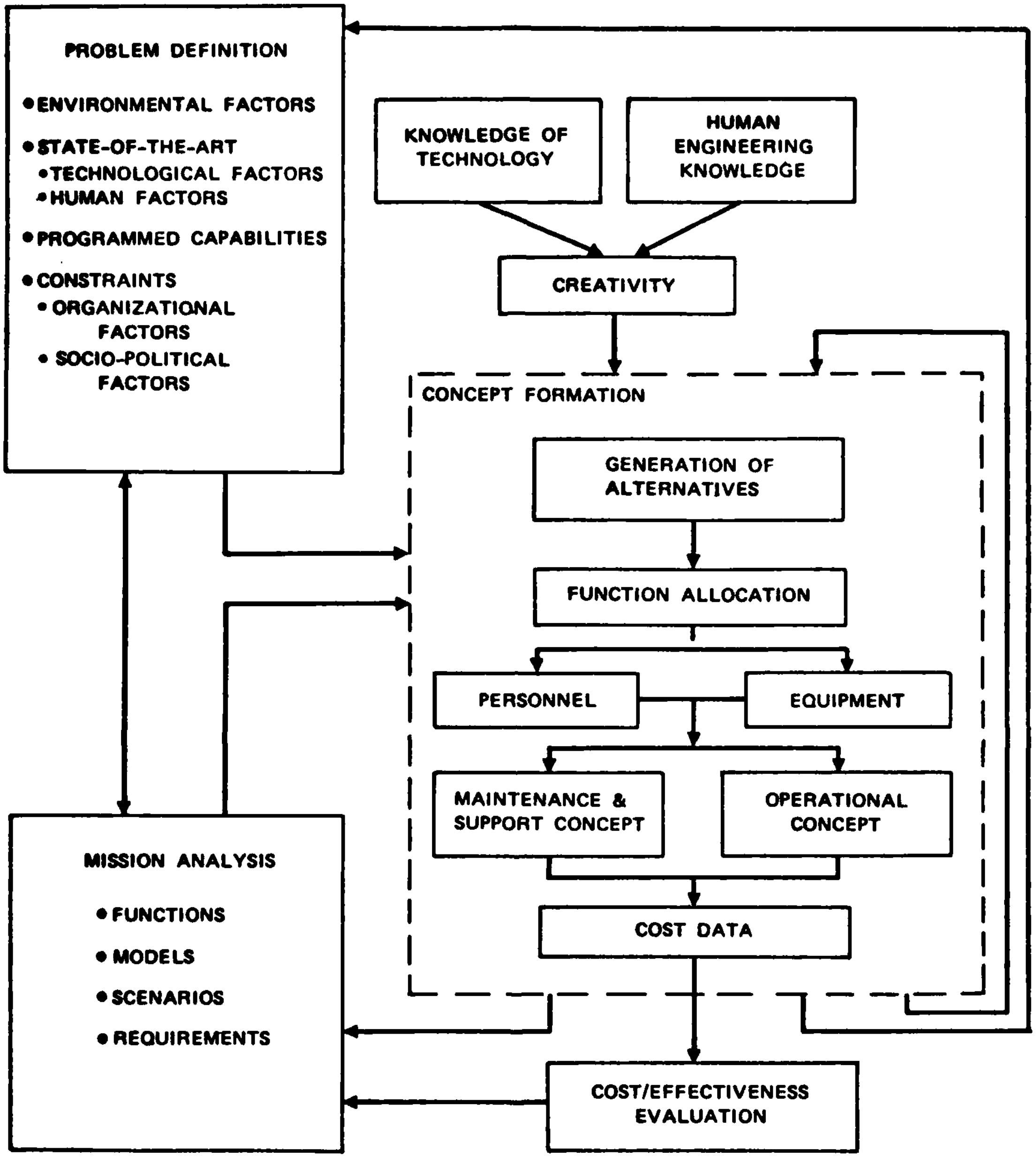

FIGURE A-5. The General Process of Concept Formation Related to Other System Analysis Phases.[47]

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[47] Schneider, R. H., et al, System Analysis Guide, Dunlap and Associates, Santa Monica, Calif. (Report No. 40-WA3-1, Contract No. N123(60530) 53431A with the Naval Weapons Center, China Lake, publication UNCLASSIFIED), October 1966.

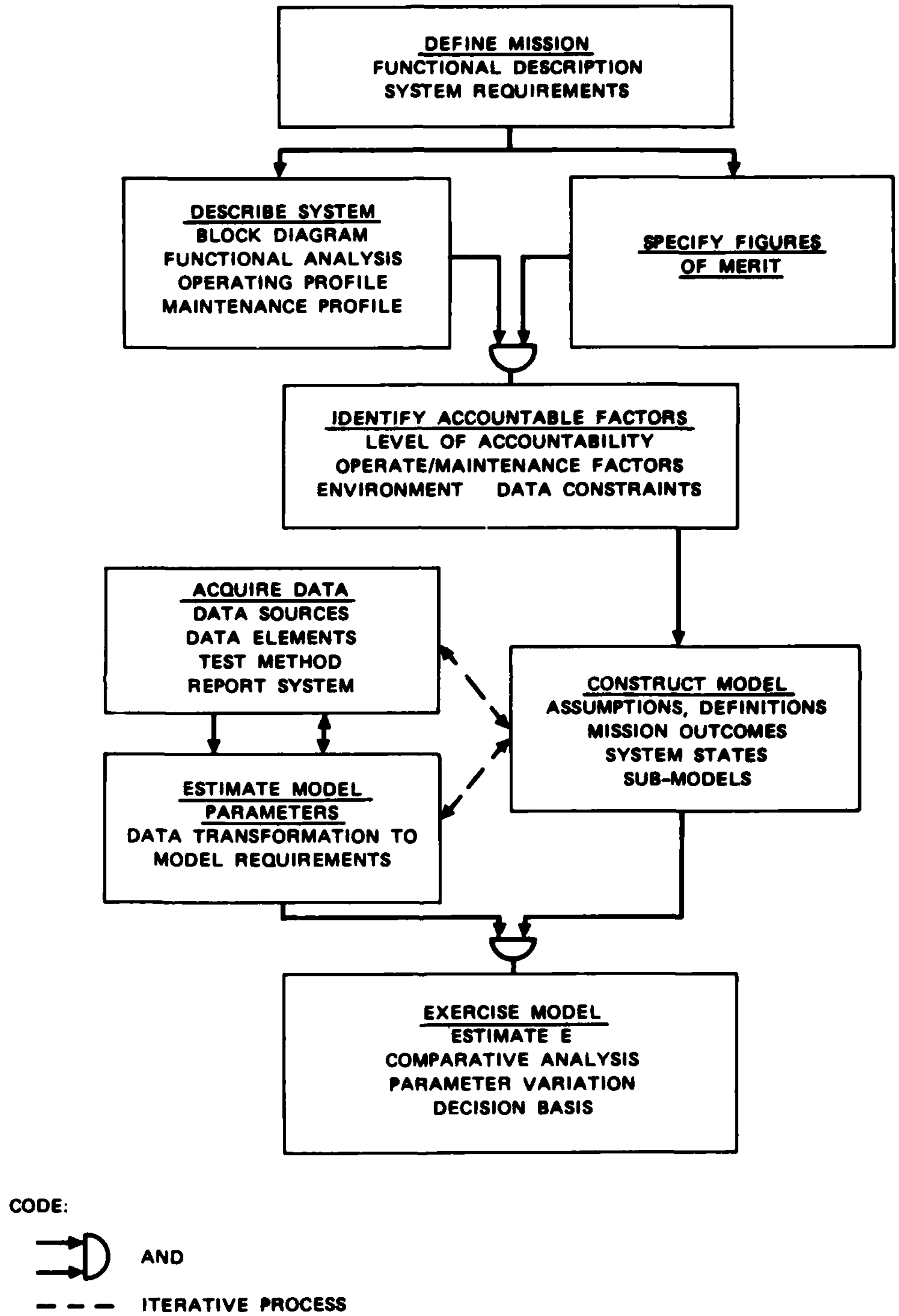

FIGURE A-6. Principal Tasks Required for Evaluation of System Effectiveness (from Hermann[21]).

SYSTEM REQUIREMENTS

1. OPERATIONAL MISSION-OBJECTIVES
2. DESCRIPTION OF CONDITIONS FOR DEPLOYMENT
3. CONCEPT OF OPERATIONS AND SUPPORT
4. OPERATIONAL PERFORMANCE REQUIREMENTS
5. SYSTEM EFFECTIVENESS CRITERIA
6. DATE SYSTEM IS TO BE AVAILABLE
7. COST LIMITATIONS
8. DEVELOPMENT PROGRAM CONSTRAINTS
9. POLITICAL CONSTRAINTS
10. DESCRIPTION OF THE TECHNICAL APPROACH WHICH IS TO BE VALIDATED, INCLUDING ANY 'OFF-THE-SHELF' ITEMS WHICH ARE TO BE USED OR TO WHICH THE SYSTEM IS TO BE MATED

SYSTEM FUNCTIONAL REQUIREMENTS

PROGRESSIVE ANALYSIS OF SYSTEM REQUIREMENTS AND CONTRAINTS TO:

1. FORMULATE TOTAL SYSTEM MISSION AND FUNCTIONAL REQUIREMENTS (FUNCTIONAL FLOW DIAGRAMS)
2. APPORTION PERFORMANCE REQUIREMENTS AND RELIABILITY VALUES TO SUBSYSTEMS (SYSTEM EFFECTIVENESS MODEL)
3. DESCRIBE FUNCTIONAL DESIGN CHARACTERISTICS TO ACHIEVE AN INTEGRATED SYSTEM DESIGN (FUNCTIONAL SCHEMATIC)
4. ESTABLISH CRITERIA AND STANDARDS FOR EVALUATION OF SYSTEM END ITEM PERFORMANCE (TIME-LINES)
5. INTERRELATE SYSTEM AND FUNCTIONAL REQUIREMENTS WITH PERFORMANCE ALLOCATIONS AND ANALYZE OMISSIONS (REQUIREMENTS MATRIX). THESE WILL INVOLVE:
   - A. PRIME MISSION EQUIPMENT
   - B. SUPPORT EQUIPMENT
   - C. FACILITIES
   - D. PROCEDURES
   - E. PERSONNEL TRAINING
   - F. LOGISTICS SUPPORT

SYSTEM DESIGN

DERIVE A COHERENT SYSTEM DESIGN TO PRODUCE A DEFINED SET OF OPTIMUM OUTPUTS FROM GIVEN INPUTS WITH RESPECT TO TIME, COST, AND PERFORMANCE MEASURES OF EFFECTIVENESS:

1. ALTERNATIVE DESIGN APPROACHES MAY BE SPECIFIED FOR DEFERRED EVALUATION AND FINAL CHOICE DURING SYSTEM ACQUISITION
2. ACQUISITION MAY BE DELAYED PENDING DEVELOPMENT OF KEY COMPONENTS
3. DESIGN OBJECTIVES OR PERFORMANCE REQUIREMENTS MAY BE COMPROMISED IF THE URGENCY TO ACQUIRE SOME DEGREE OF THE SPECIFIED OPERATIONAL CAPABILITY SO DICTATES

SYSTEM TRADE OFF STUDIES

CONCERNED WITH ACHIEVING OVERALL SYSTEM OPERATIONAL CAPABILITY BY:

1. DEVELOPING A DESCRIPTIVE SYSTEM MODEL, OR ALTERNATIVE MODELS TO INTEGRATE INPUTS, OUTPUTS AND SYSTEM STATES IN A REAL TIME OPERATIONAL ENVIRONMENT
2. EVALUATING ALTERNATIVES AND VARIATIONS IN DESIGN AND SELECTING 'BEST-FIT' SYNTHESIS OF SOLUTIONS FOR MANAGEMENT CONSIDERATIONS IN RELATION TO PERFORMANCE.
   - A. DETERMINING HOW THE BEST ACHIEVABLE DESIGN SOLUTION EXCEEDS OR FALLS SHORT OF REQUIREMENTS
   - B. IDENTIFYING WHEN DESIGN AND DEVELOPMENT OF A SYSTEM ELEMENT REQUIRES ACHIEVEMENT OF NEW TECHNOLOGY GOALS AND ESTIMATING PROBABILITY OF SUCCESS WITHIN SYSTEM DEVELOPMENT CONSTRAINTS ('HIGH RISK AREAS')
   - C. IDENTIFYING PROBLEMS REQUIRING SPECIAL MANAGEMENT ATTENTION AND MAXIMUM VISIBILITY FOR MONITORING PROGRESS IN DEVELOPMENT

FIGURE A-7. Basic System Engineering Parameters As Adapted from Chase[10].

APPENDIX B

MEASURE OF EFFECTIVENESS

There are a number of sources of information on measures of effectiveness, but a primer or textbook on the subject has not been located. Ideas about properties of good MOEs, and the procedures for developing MOEs for a particular study can be obtained from selected quotes from the literature.

Criteria for MOE (taken from Anderson, et al[22])

Measures of effectiveness have to be developed for each new study and test because no one set of MOE has been forwarded that fits all situations. Two of the criteria for selecting final MOE from a list of considered measures are given below.

1. The first criterion is that a MOE express the extent to which a system meets the best possible performance. A MOE may express system performance as a proportion of maximum performance. For example, percent of targets hit and probability of hit are MOE, and firing rate is a measure of performance that can be converted into a MOE by dividing it by maximum required (or desired) firing rate. Obviously, making the best required performance the denominator of the measure means that MOE can only be developed in keeping with the objectives of a system.

2. The second criterion for MOE is that they should be consistent in quantities and units. This facilitates intra- and inter- system comparisons. This criterion requires that the analyst consider how the numbers expressing the MOE are to be manipulated mathematically in order to derive conclusions concerning the effectiveness of the systems being evaluated.

Figure B-1 illustrates that one "effectiveness" results from a fixed scenario. In practice, however, if the effectiveness is not as high as desired, the operating conditions can be changed and the operators can be trained to improve the situation (Figure B-2). Figure B-3 illustrates that an effectiveness analysis is an iterative procedure, and can affect the system design, tactics selection, and training program for a system under development.

This iterative nature in the design and use of a system makes it difficult to come up with a "final" anlaysis or model. The analysis should be structured at the outset so that changes can be made without too much difficulty (e.g. a modular design).

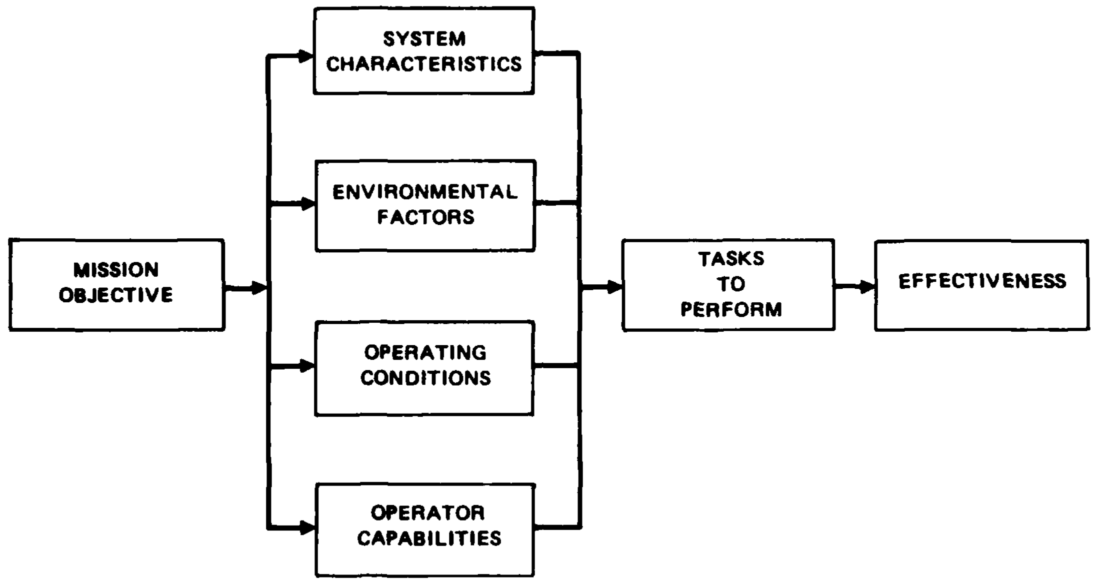

FIGURE B-1. Open-Loop System Effectiveness Diagram.

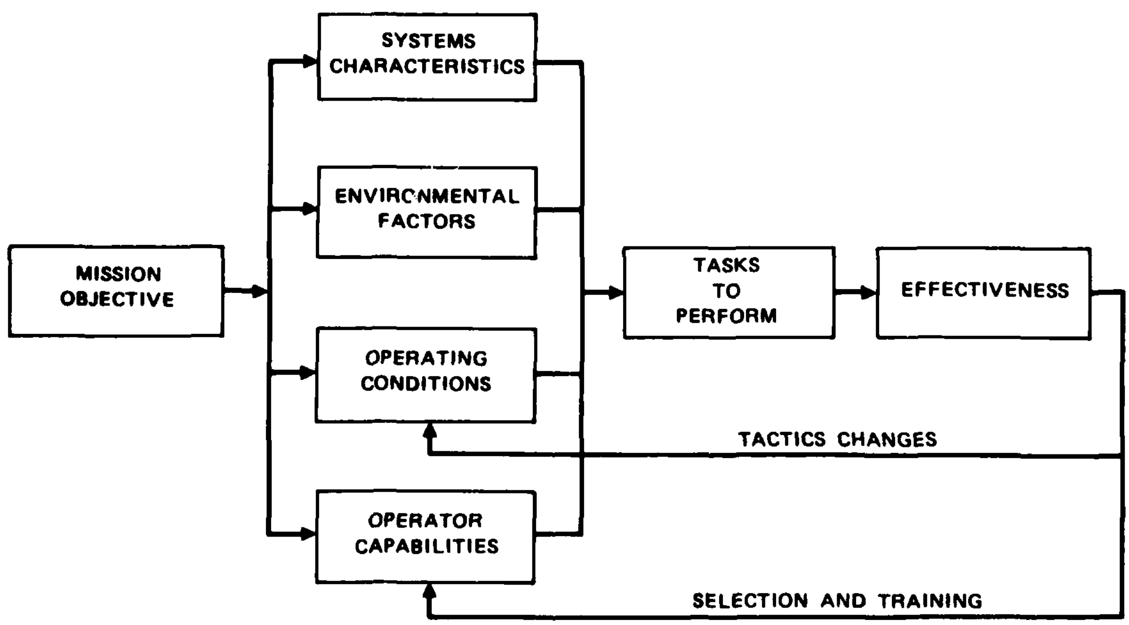

FIGURE B-2. Existing System Effectiveness Diagram.

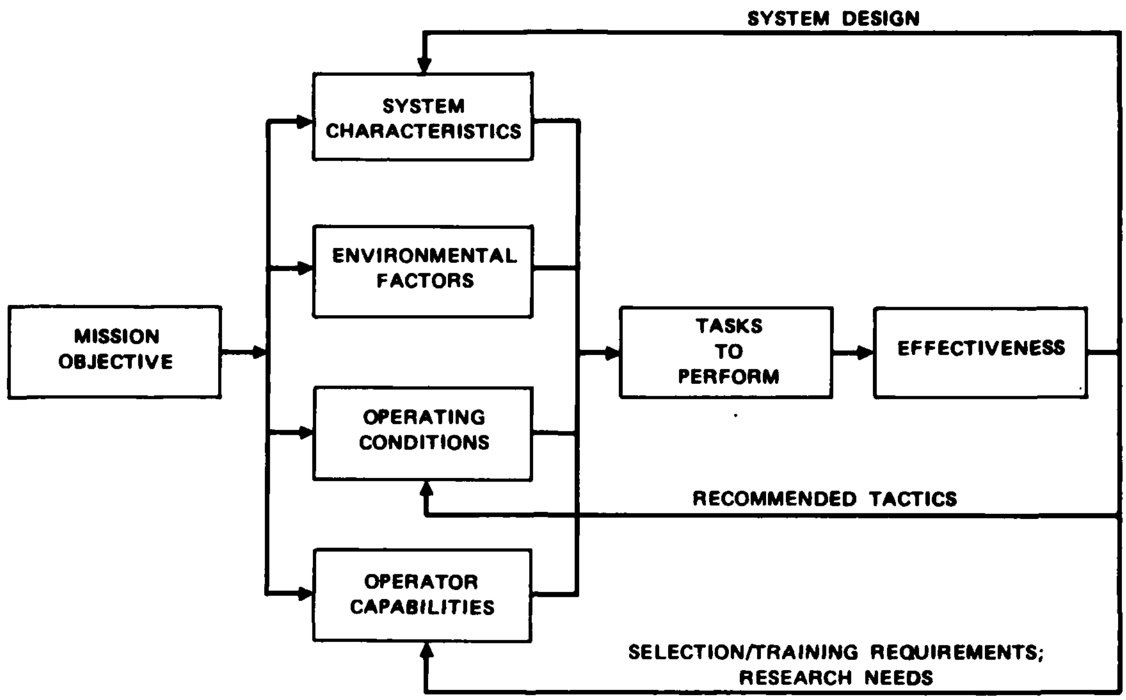

FIGURE B-3. New-System Effectiveness Diagram.

APPENDIX C

AVAILABILITY OF PERFORMANCE DATA

For many years, analysts have had difficulty in finding appropriate operator performance data for use in their studies. Some quotes from the literature will give the reader an idea of the difficulties.

> "At first glance, the massive amount of human performance data existing in psychological journals and technical reports might seem more than sufficient for application to man-machine models by the naive observer. Several attempts have been made to extract relevant data from that literature. However, none of the resulting "data stores" appears so far to have any substantial degree of validity or utility, and there is considerable doubt that the literature extraction process will ever produce data appropriate to modeling purposes." (from Smith, et al,[48])

Or, Meister[15]:

> "One wonders why there is such a lack of available ergonomic data, considering the large number of experimental studies turned out annually. Attempts have been made to translate data from the general behavioral literature into ergonomic equivalents (Meister and Mills 1971) but the difficulty appears to be that the tasks performed and the stimuli presented in general psychological studies bear little resemblance to the real world situations faced by the systems ergonomist."

DeGreene[17] also recognizes the problem:

> "The problem of mismatch between operational data needs and research outputs has previously been discussed in the literature. Variously emphasized have been the lack of transferability of laboratory results to the real world, fragmentation of and poor communications between the scientific

---

[48] Smith, Russell L., et al, "The Status of Maintainability Models: A Critical Review," Human Factors 1970, 12(3), pp. 271-283.

> disciplines, preoccupation with outmoded concepts of 'basic' research, continued dependence on obsolete paradigms stemming from earlier eras of scientific research, the nature of the basic unit of analysis, lack of a systems approach and lack of integrating theory."

As does Simon[49]:

> "While human factors practitioners have made significant contributions toward easing the job of the human operator and making system performance more effective, the contributions of the human factors scientists -- the experimenter -- have been modest. Today, one has to search diligently among piles of published papers to find among the trivia and the isolated facts, data that is sufficiently generalizable to answer questions concerning the design of future systems and to do so quantitatively."

"So what is a body to do"? as the grandmother in the soap opera would ask.

Blanchard[50] illustrates how data availability was estimated in one case, and discusses the lack of data and the possibility of establishing a store of data. Survey respondents had the following opinions:

> "Utility of Data Currently Available
>
> "Perceptions of survey respondents were also gained on the utility of three sources of data which are generally available and in use. Those sources were: (1) experimental literature; (2) guides and manuals; and (3) fleet exercise data.
>
> "The availa^le experimental literature was perceived to represent a highly limited source of useful data. Several respondents indicated that the time and effort spent searching the literature for data seemed to be seldom worth the effort. Most respondents felt that the experimental literature was essentially non-applicable to applied work on Navy systems. Basically, that was due to questions as to the generalizability of the data and difficulty in determining the experimental circumstances surrounding data collection and reporting.

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[49] Simon, Charles W., Analysis of Human Factors Engineering Experiments: Characteristics, Results, and Applications, Canyon Research Group, Technical Report CWS-02-76, August 1976, Westlake Village, Calif.

[50] Blanchard, R. E., "Human Performance and Personnel Resource Data Store Design Guidelines," Human Factors 1975, 17(1) pp. 25-34.

AD-A146 326 THE HUMAN OPERATOR AND SYSTEM EFFECTIVENESS(U) NAVAL WEAPONS CENTER CHINA LAKE CA R A ERICKSON JUN 84 NWC-TP-6541 2/2

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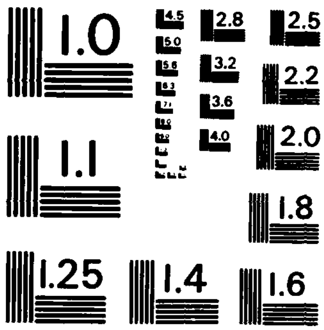
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4.0
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1.8
1.25
1.4
1.6

"Human engineering guides and manuals were considered to have only limited utility in serious system design efforts where the practitioner is attempting to obtain quantified estimates of human performance relative to various hardware design and environmental parameters.

"Fleet exercise data were not considered to be a highly useful data source since the data were felt to be essentially undependable. The attempt has been made on numerous occasions to use observers to obtain real-time measures of performance. However, the data are felt to be vulnerable to errors made by the observers. Consequently, such data are viewed with suspicion by most users."

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